DEPARTMENT OF AGRICULTURE
CENTRAL EXPERIMENTAL FARM
OTTAWA - - CANADA

DIVISION OF BOTANY

SMUT DISEASES

OF

CULTIVATED PLANTS

Their Cause and Control

BY

H. T. GÜSSOW,
Dominion Botanist.

Bulletin No. 73

Published by direction of Hon. MARTIN BURRELL, Minister of Agriculture, Ottawa, Ont.

MARCH, 1913

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The Honourable
The Minister of Agriculture,
Ottawa.

SIR,—I have the honour to submit for your approval Bulletin No. 73 of the Experimental Farm Series, on Smut Diseases of Cultivated Plants, their Cause and Control, prepared by the Dominion Botanist, Mr. H. T. Güssow.

This publication deals with the identification, treatment for prevention and, in some measure, for eradication, of smut diseases of our common crops. These diseases work annually immense injury to Canadian agriculture, hence any reliable information on this subject that can be put into the hands of the farmer should be of great value to the country as well as to the individual. The extent of the injury wrought the farmer by these various smuts can be grasped only after one has observed their effects in particular instances and then paused to calculate the sum total of the losses. To such as have had opportunities of observing the losses caused by these fungi in both lessened yields and lowered grades of grain the estimate of $15,000,000 loss to the Canadian farmer, per annum, will not seem in the least exaggerated. In my opinion, this bulletin should be very widely distributed throughout Canada but, of course, more particularly in the prairie provinces.

I have the honour to be, sir,

Your obedient servant,

J. H. GRISDALE,
Director, Dominion Experimental Farms.

OTTAWA, March 25, 1913.

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SMUT DISEASES OF CULTIVATED PLANTS.

THEIR CAUSE AND CONTROL.

BY

H. T. Güssow, *Dominion Botanist.*

I.

GENERAL REMARKS.

Smut Diseases not confined to cultivated plants.—The well-known conspicuous diseases commonly designated as 'Smut Diseases' are by no means exclusively confined to cultivated or economically important members of the natural order of grasses —among which our cereals, for instance, are the most valuable—but they also occur in other plants widely distant in relationship from the grass family. Their importance to the farmer diminishes as the properties of the plants attacked become of less economic value. For this reason, the following pages are devoted to a study of the more important forms occurring on plants of agricultural value.

'Smuts' caused by microscopic fungi, their nature and action on the host plant.—All smut diseases are caused by minute parasitic plants known as microscopic fungi. Many of these minute plants—popularly referred to as moulds—are of decidedly destructive habit, owing to their parasitic mode of life. Their parasitism is due to the fact that all fungi are incapable of manufacturing their own food and, therefore, depend for their sustenance upon ready prepared food, which the parasitic fungi find in the tissues of the plant—or host plant, as it will be called for our purpose—on which they live. As a result of such relationship, they either seriously interfere with, or frustrate altogether, the purposes for which certain plants are cultivated—the production of grain in the case of cereals—or may finally cause the death of the plant on which they depended so long for their livelihood. The various fungi causing smut diseases are among the best examples of parasites, and on occasion may prevent entirely the production of grain. The smut fungi, like other related microscopic fungi, possess delicate vegetative organs—the mycelium—by which they live partly or exclusively in the cells of the host plant. After having gained sufficient strength by the absorption of food from that plant, they produce an abundance of generative or reproductive organs—the spores—which penetrate to the surface of the parts of the infected plant involved, where they produce more or less prominent symptoms (smut heads, smut balls or smut boils). The disturbance of the growing smut fungus within the cells of the host plant may be of so slight a nature as not to be perceptible by any outward symptom until the fungus has reached maturity and produces its spores. At times, enormous spore masses are produced within the cells of the host plant, so that the latter cannot resist the increased local pressure from within, and the tissues involved expand and finally burst open, when the spores appear on the outside in the form of blackish or brownish dust.

The spores of smut fungi and their dispersal.—When this stage is reached, spore dispersal follows immediately. Fungus spores are comparable to seeds of more highly organized plants inasmuch as they reproduce their kind. They are, however, not seeds in the true botanical sense.

The spores of smut fungi are minute, round or roundish plant cells, much finer and lighter than road-dust or other atmospheric impurities, and are readily caught by slight air currents, by means of which they are disseminated. The wind as an agent for the dispersal of spores seems often to be regarded as a far more important factor than it really is. No doubt, where badly infected grain is threshed, the wind may play an important role as a dispersing agent of the spores which may issue from the threshing machine in the form of black clouds of spore dust, but the matter is different under more natural conditions, i.e., in the field. Experiments demonstrating the distance of the dispersal of spores produced in a smutted grain field have been carefully conducted in widely different localities (Russia, Germany), and coincided so closely in their results that the conclusions arrived at may be considered reliable. It was found that no smut spores could be demonstrated in 'spore traps' farther distant from badly infected fields than 250 yards. Prof. Buller, of the University of Manitoba, in his able 'Researches on Fungi,' expresses his opinion as follows: 'The wind, when travelling several miles an hour, must frequently carry the spores from a fruit body (speaking of higher fungi) for very long distances. Owing, however, to their steady fall at the rate of 0·5–5 mm. per second, sooner or later all spores must reach the earth. The larger the spores the sooner they will settle.'

The wind is, no doubt, one of the natural factors concerned in the dissemination of fungus spores, but the smut diseases are not entirely spread by that agent. The hairiness of the wheat grain (see plate 1, fig. c, d), the small cracks or deep lines in the hull of the oat, the rough seed coat of barley, provide sufficient means for the adhesion of spores. By sowing such infected seed the disease is naturally spread. Or the smut spores may ultimately reach the soil by way of infested manure, farm implements, or machinery covered with fungus spores. The smut spores will also find their way into the barn, will infest the grain bin and contaminate new grain that may have been quite free from it previously. Care should also be taken to use clean bags, especially for seed that has been treated, or re-infection with smut spores is liable to take place. The old bags that have contained smutty grain may be freed from the spores by dipping them into a strong formalin solution, or into boiling water, when, after drying, they may be safely used again. All these points should be borne in mind particularly where smut-infected grain is threshed.

Threshing machine, an important agent responsible for the spread of smut diseases.—We cannot conclude our discussion of the ways and means of dispersal of spores without referring to the practice in vogue of moving threshing machines from one farm to another. While in ordinary farming practice no doubt of very great benefit in dealing with the problem of threshing grain, this practice forms one of the most important agents responsible for the wide distribution of smut diseases and their introduction at times to farms previously quite free from smut. A machine which has been used for threshing smutted wheat is so fully infested with spores that any grain subsequently threshed—unless the machine is properly sterilized after use—will become liable to infection.

The importance of the threshing machine in serving as a means of disseminating weeds, is to some extent recognized, as may be seen by the 'Weed Acts' in force in some provinces, making it compulsory for the men in charge of the threshing machine to clean it, as well as the wagon and racks or any other part of the outfit, before removing them from a farm. But as regards the dissemination of smut diseases, the necessity of making it compulsory to fumigate the outfit is by no means adequately dealt with. A machine which has been used for threshing grain infected with smut will contain millions of smut spores which it will scatter all over the fields or roads over which it travels, besides infecting the next lot of grain to be threshed. The successful control of smut diseases will depend very largely upon the exercise of every care and the adoption of means by which the possible ways of dissemination are controlled. The method of treatment alone will not dispose of smut diseases; it also is necessary to

cut off all means of infection. It is very advisable to make it compulsory not only to clean the machine after use in order to prevent the spread of weeds, but to clean it also from the disease germs of smut. In the absence, at present, of any legal enactments farmers are strongly advised to insist upon the use of clean machines, and not of those which are liable to introduce diseases which it will cost much more time and money to control, than that required for the initial cleaning of the machine.

Where a farmer has succeeded by years of careful treatment in eliminating or practically eliminating the smut diseases from his farm, the use of a smut-infected machine will undo the work of years during one single process of threshing.

We realize that the time during which such cleaning operations would have to be performed is probably one of the busiest of the year, and also that many hundreds of threshing machines may be at work at one time, but this fact emphasizes rather than diminishes the necessity of guarding against the spread of smut diseases. We suggest that it be made compulsory, and that the provincial authorities be induced to pass the necessary legislation for cleansing threshing machines thoroughly before using them on new premises. The operation which would be required to destroy the smut disease germs is as simple as it is effective. After sweeping the machines inside and out to get rid of the weed seeds, the foreman of the gang should immerse some old bags or sacking in formalin—one pound to one gallon of water—and place them inside the machine, after which, all openings should be closed or covered up to retain the formaldehyde which evaporates. If thoroughly air-tight, or as air-tight as possible, the fumes will very effectively destroy the vitality of any smut spores while the machine is travelling from one farm to the other. After five to six hours fumigation, the inside of the machine contains no living smut spores. The outside of the machine, wagon, racks and any implements, etc., in use may be rapidly sterilized by means of an ordinary knapsack sprayer filled with the formalin solution mentioned before. The whole procedure would not require more than one-half hour after a little experience, and would cost only a slight amount.

The farmers should insist on seeing this treatment carried out, and the thresher should be provided with a card setting forth that this treatment was carried out before leaving the farm, which card should be signed by the farmer and be demanded by the next farmer on the list, when the machine arrives on his premises. Farmers by exercising such care would greatly aid in the reduction of smut diseases throughout important grain-growing areas.

The vitality of the smut spores.—(a) Natural.: The spores of certain smut diseases which reproduce entirely by spores, as, for instance, stinking smut of wheat, covered smut of barley, the oat smuts, etc., are very long-lived; under certain favourable circumstances, the spores may retain life for seven or eight years. In a dry condition, they are also exceedingly resistant to frost. Where reproduction depends on spores only, nature has endowed them with great powers of resistance, but where so-called vegetative reproduction occurs—as in the true loose smuts—the spores lose their vitality after five to six months. In these cases, there is no necessity for a long life of the spores, inasmuch as the fungus is dependent for reproduction upon the mycelial filaments within the tissues of the seed, as will be explained later. The question of the longevity of the spores, of course, closely concerns the control measures for the various smut diseases. It also clearly proves that storing grain infected with smut spores would reduce the germinative power of the seed rather than that of the spores, at any rate no advantage would be gained from such a practice.

(*b*) *The vitality of spores passing through the bodies of animals.*—The next point to consider is the germination of spores which have passed through the bodies of animals fed on smut-infected food. This point is of practical importance, considering the fact that animal manure contains ingredients having a decidedly beneficial influence on the germination of smut spores, and thus they may retain their power of infection for a considerable period, when eventually such manure is spread on land.

The natural contamination of manure with smut spores should be carefully guarded against, hence it will be important to know whether the life of the smut spores is destroyed by the juices of the stomach or whether smut spores should be still considered active agents in disseminating the smut diseases when, contained in the manure of animals, they eventually reach the soil. Naturally, the most important smut fungi concerned in these investigations are those causing seedling infection, as for instance, stinking smut of wheat. Partly for this reason and partly because these spores may be obtained in sufficiently large quantities to render feeding experiments of value, the spores of this fungus are generally used for the purpose. The most recent experiments on that point may be summarized as follows: 'The passage through the bodies of animals of all kinds, of stinking smut spores, resulted in destroying the germination of the great majority. Only those passing through pigs retain their germination to a greater degree.'

Hence it will be seen that there still exists enough danger from the spreading of these diseases by spores ingested by animals and contained in their manure.

Is smut-spore-infected food injurious to the health of animals?—There have been discussions from time to time in the agricultural press with reference to the probable injuries to live stock fed on smutted grain or food. Important text-books even now point out the danger of such practice. It is said that smutted grain, both seeds and straw and whether dry or green, is injurious. Disturbances of the digestive organs, loss of flesh, flow of saliva, paralysis of the hindquarters and the muscles of the mouth and throat, and in some cases death, are the symptoms not infrequently recorded.

The results obtained, however, from careful inquiry and experiments do not confirm this serious arraignment, and we are led to believe that, as is often the case in such investigations, the conclusion is one of conjecture.

Quite recently this important question has again received careful attention at the Agricultural Experiment Station, Rostock, Germany. The conclusions of these experiments are briefly summarized here:—

'Notwithstanding the claim that material containing smut spores [notably stinking smut of wheat] fed to animals has resulted in causing injuries to their health, not one single instance could be discovered showing that any indisposition of animals could be attributed with absolute certainty to smut-spore-contaminated food. On the contrary, scientific experiments with animals under constant observation, to which large quantities of pure smut spores were given, have shown that the claims as to the injurious nature of smut spores have been exaggerated.'

The animals subjected to experiment were pigs, cows, horses, sheep, rabbits, chickens and pigeons. Although large quantities of smut spores were fed to the animals—often for several weeks—the observers are not able to express an absolutely definite opinion. It must be realized that animals show frequently, during feeding experiments of any kind, certain indispositions, which may or may not be a result of the diet. The same was observed in this series of experiments and led the author to conclude:—

'It appears to us advisable not to recommend the feeding of smut-spore-contaminated food, as it cannot be declared harmless under all circumstances. Pregnant animals, and those naturally subject to slight intestinal troubles should receive no such food. In the opinion of other writers, smut spores contain a poisonous substance which directly acts upon the gravid uterus, hence care is necessary. The difficulty of ascertaining the true cause of indisposition of the animals experimented upon still leaves this important question undecided.'

Dr. McAlpine, the Australian Government Plant Pathologist, states 'that it is interesting to note that the well-known boils of corn probably contain the same alkaloid as the ergot and the fluid extract is used in a similar manner.' The peculiar

action of ergot on the gravid uterus is, of course, well established, as is the truly poisonous character of this fungus body when given to animals in food.

It may be interesting to cite that we recently examined similar smut boils on Chinese water rice (*Zizania latifolia*), due to the smut fungus *Ustilago esculenta* P. Henn., but which, we are assured, form an important article of food in China.

As regards oat smut, in Bulletin 7 of the Government of the Northwest Territories, p. 6, the following opinion is given: 'When abundant in a crop which is cut for green feed, oat smut may cause irritation and congestion. A number of fatalities amongst cattle in northern Alberta have been attributed to this. In Montana, a lot of cows were fed on smutty hay, and within twelve hours after the first feed, one-half of them died with symptoms of gastritis and cerebral excitement. No more of the hay was fed, and no more deaths resulted. A post-mortem examination showed the stomach much distended.'

We find these opinions more or less unanimous on the point that food contaminated with smut is at any rate unwholesome, and, although the matter is not definitely cleared up, we advise farmers not to run any risk of losing animals by giving them food of a so decidedly suspicious nature.

Reproduction of smut diseases and infection of the host plant.—We have already discussed the production of the smut spores and their means of dispersal. The time of the dispersal of smut spores involves the question of the reproduction as well as that of the mode of infection of plants. When the seed of a plant has ripened, in annual plants, the life of this plant terminates with the fulfilment of its purpose, viz., that of reproduction. The continuance of this species of plant rests then with the seed. Likewise, when the smut spores have ripened, the life of the fungus has come to a termination, and reproduction depends upon the spore reaching eventually an environment favourable for its development into a new generation. The new generation of the smut fungus will appear to us in the form of the well-known smut diseases. After being produced, the spores of some smut fungi require to reach the soil in order to propagate their kind. This purpose is accomplished in stinking smut of wheat, covered smut of barley, naked and loose smut of oats and others, by adhering to the outside of the grains, and thus being sown when the grain is sown. When finally the spore has reached the soil, germination takes place and the spore produces a stout, short piece of mycelium from which secondary or even tertiary spores may develop, which by means of infection threads attack the young grain seedling which has grown meanwhile. This mode of infection is known as seedling infection.

Some higher plants, besides producing seeds, reproduce themselves also by means of perennial 'roots' (Perennial Sow Thistle, etc.). This method is known as vegetative reproduction. In some smut fungi there exists a similar mode of perpetuation, although the spore itself still plays the important role. In the so-called loose smuts of wheat and barley, the spores are ripe at the time of flowering of the barley or wheat, and the spores shaken loose by the wind fall upon the female organ of the flowering grain, where they germinate—in a manner similar to that of the pollen grain when fertilizing the ovule—push their way into the ovary of the flower and remain dormant in the form of delicate mycelial portions without preventing the formation of a grain, which, though containing the germ of disease, is apparently quite normal. Plants grown from such seed will eventually show the loose smut disease. This mode of infection is termed flower infection.

A third method of infection occurs in Indian corn. Here the spores when ripe may immediately produce new infections. While in those kinds producing seedling and flower infection a period of rest is necessary, the corn smut may spread in the field to a considerable extent the same season. Infection of the corn plant may take place at any time and at any young and tender portion of the whole plant.

The importance of the knowledge of the various modes of infection is apparent, when dealing with the control of the various smut diseases. In one instance, the

spores must be prevented from reaching the soil, in the other, the germ within the grain must be prevented from doing the damage, and, in corn smut, control depends upon the extermination of the source of infection by another method.

Smut diseases influenced by certain conditions.—During the experiments carried out at the Central Experimental Farm, certain peculiar observations were made indicating that the development of smut diseases is dependent upon conditions of various nature.

It has been our experience when sowing wheat infected with the spores of stinking smut, that our check plots remained free from smutty heads just as the plots did which were treated. Such difficulty was never experienced with oat smuts. The opinions of other investigators were obtained on this strange point, with the result that our observations were confirmed in a large measure.

Dr. C. E. Saunders, the Dominion Cerealist, who can speak with authority and from close experience of Ottawa conditions, expresses himself that although he does not make it a usual practice to treat the wheat for his experimental plots for stinking smut, this smut may be considered of rare occurrence on the Ottawa farm. It is also the general belief that, as far as eastern localities are concerned, stinking smut is of little economic importance. In the West, the conditions are very different.

Dr. Edw. C. Johnson, of the office of grain investigations, United States Department of Agriculture, was also communicated with, and expressed his experience in a letter to me as follows:—

'Your inability to produce stinking smut in Ottawa has been duplicated in my own experience many times. In order to test the various methods of treatment, I have inoculated seed heavily with viable smut spores and then have planted it, treating some and using some for control. The resulting plants have been all clean, even in the control which should have been smutted. Undoubtedly there are many points in the physiology of this smut which are not yet understood, particularly with regard to the conditions influencing infection phenomena.'

As is correctly suggested by the investigator, there remain a number of unexplained features concerned in the successful infection of wheat by stinking smut.

Different dates of sowing apparently influencing attacks of smut fungi.—The points raised in the former paragraph have also engaged the attention of European workers. Some of these furnish experimental evidence indicating that it is not a peculiar resistance of the plant itself that is to be considered as concerned in these surprising escapes from infection, but rather that a successful infection of plants is dependent upon one or a number of outside factors, favourable or the reverse, to the development of the smut fungus. We will refer here to some striking examples in this respect. A large field of winter wheat which had been sown about the end of October was much attacked by stinking smut (about 60 per cent), while the adjacent fields belonging to the same farmer, under the same variety of wheat and treated in a similar manner, but sown early in October, showed no sign of infection. Another farmer had sown spring wheat (without previous treatment for smut) in one field at the beginning of February, and in another in the middle of March. At harvest time 30 per cent of the first sown and less than 5 per cent of the latter sowing were infected with smut.

In order to investigate this relation of the date of sowing, experiments were undertaken by Dr. Munerati (Jour. d'Agri., part 76, Vol. II, Paris, 1912) which gave results of considerable significance, which are quoted in the following table:—

Date of sowing.	Infected wheat.	
	Treated.	Untreated.
October 11	0%	1%
October 21	0%	3%
November 10	1%	10%
November 22	4%	90%
February 10	2%	30%
March 10	0%	5%

The results obtained indicate that the very different climatic conditions no doubt prevailing at the time of the various sowings have influenced the rate of infection. We have made similar observations concerning the virulence of attack depending upon the different date of sowing of turnips in the case of the well-known club root disease. Dr. Munerati in explanation of the above table states: 'A grain which is covered with smut spores (*Tilletia*) and has not been treated with solutions, escapes the attack of the parasite if sown early, but the same grain will, on the contrary, be infected by the disease, if sown when the temperature is low and the plant is making little growth. The contrary is the case in spring wheat. In practice, the later in the autumn and the earlier in the spring wheat is sown, the more necessary it is to treat the grain with fungicides.' Canadian conditions may be vastly different, but that such escapes from infection in the case of wheat are known here is beyond any doubt. What, now, are the effects of such evidently climatic conditions on the decrease or increase of smut respectively?

The influence of temperature on the germination of wheat and of smut spores is well known. The lower the temperature, the slower is the germination of wheat. Wheat sown in experimental pots kept at so low a temperature as 34-36° F., i.e., a few degrees above freezing point, began to germinate, but its progress was very slow. When kept at 77° F. the germination took place after some 20 hours, and the period from germination to the production of the first leaf which pushes through the protective sheath was considerably shortened by the higher temperature.

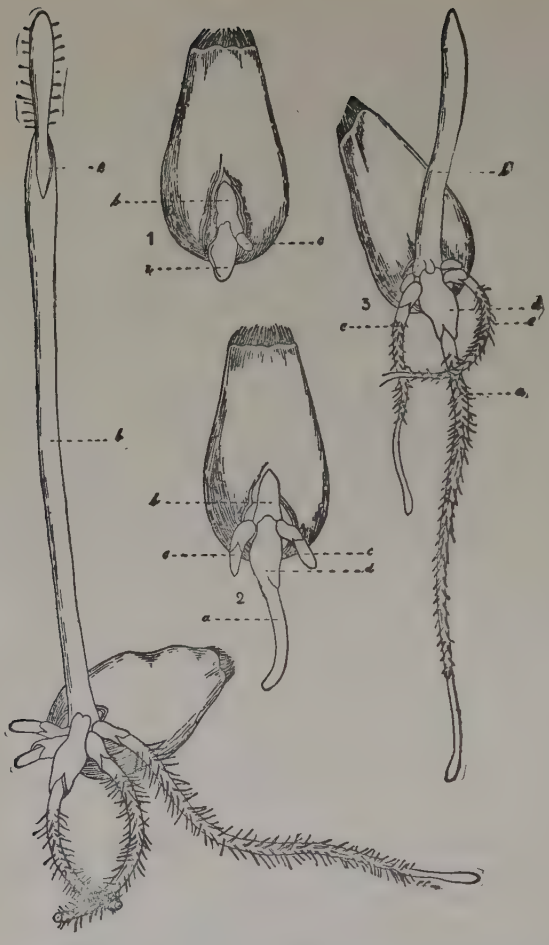
Smut spores (*Tilletia*) do not start into active life at all before 41° F. is reached, while their germination maximum is about 77° F.

Bearing these facts in mind, it is easily understood that wheat beginning to germinate at a lower temperature than the smut spores, may be just in the most susceptible stage when the latter begin their activity. On the other hand, when considering that, under normal circumstances, the young wheat is only for some eight to ten days in a fit condition for the fungus' attack, the plant may have outgrown this stage before the fungus succeeded in effecting an attack. Thus it may be realized what an important rôle the temperatures prevailing at the time of germination really play.

Infection of the wheat plant takes place only during the normally short period from the beginning of the germination to the point when the first green leaf is ready to push through the colourless sheath in which it is enclosed (see fig. a-e). That the rate of development may be greater in some varieties of wheat than in others is indicated by the fact that Early Ohio wheat has shown itself in Germany to be very immune from stinking smut. This variety germinates far more quickly than any other. However, even this wheat may be subject to a considerable amount of smut, depending upon the different dates of sowing, anything from 0 to 62 per cent of smut showing.

Varietal susceptibility of wheat towards stinking smut.—From these observations we may conclude that the different rates of infection of different varieties of wheat are not due to any special degree of immunity or susceptibility, but rather to outside conditions of which temperature seems to be the most important. But the observations of the different rates of infection have been taken into account by plant breeders who saw in them characters worthy of propagation for the purpose of breeding resistant varieties. We firmly believe that the underlying scientific principles concerning the fungus itself and its attack of the host plant are worthy to be taken into consideration wherever work is carried on along the lines of disease resistance. It has been shown that the fact that a variety may escape infection is not a proof or even an indication of its being particularly disease resistant.

Smut spores hibernating in the soil.—The question whether smut spores lying in the soil over winter play a part in carrying over smut disease from year to year is also of importance. To begin with, as far as the true loose smuts of wheat and barley



Text figure 1. Figs. 1—4 showing various stages of germination of wheat during which infection by stinking smut spores may take place : (a) primary rootlet, (b) stem, (c) secondary rootlets, (d) protective sheaths, (e) point where first green leaf pushes through the sheath, after which stage no infection occurs. (Drawings copied from set of diagrams "The life of the wheat plant" issued by the Royal Agricultural Society of England, prepared by Francis Bauer under supervision of Dr. Wm. Carruthers, F.R.S. Originals in Museum for Nat. History, Kensington).

are concerned, we can, from the beginning, exclude them from this discussion, bearing in mind what has been said about the manner of infection of the plants by these forms of smuts.

As far as the other kinds of smuts are concerned which perpetuate themselves directly by means of spores, the conditions of the Eastern and Western provinces are very different.

In the East we can take it as a fact that stinking smut, at any rate, is not carried over by the spores resting in the soil. In certain European countries, the question of conveyance of this smut through spores resting in the soil is also regarded as of little or no importance.

As far as the West is concerned, this matter has a totally different aspect. Mr. G. H. Clark, the Seed Commissioner of the Dominion Department of Agriculture, expresses his conviction that the spores of stinking smut produce a marked infection

in subsequent crops grown on fields on which they have been blown in thick clouds issuing from a thresher. Other information collected on that point confirms this opinion. We have prepared plots on the Experimental Farm in Ottawa by mixing viable spores with soil before the beginning of winter. In spring, grain was sown thereon, but no smut was noticed. But then we failed to produce stinking smut in other ways. This very curious difference of behaviour was made the subject of some experiments at Ottawa which we consider throw some light on the subject. We consider this difference mainly due to unsuitable climatic conditions which exert an injurious action on the smut spore in the East, while in the West these conditions may not exist. It is not due to frost alone. During the winter we exposed smut balls of stinking smut to freezing by enclosing a small stoppered glass tube containing the spores in a vessel filled with water and allowing this to freeze solid, the temperature falling to 20° below zero more than once. After being enclosed in a lump of ice for fully three months the spores on examination were found to be perfectly normal, though, of course, they showed then no signs of germination. The germination was then tested in artificial cultures and gave fully 100 per cent living spores. In a similar experiment dry smut spores were exposed to frost. These, too, showed no decrease in germination. Thus it was shown that the action of even severe low temperatures does not affect the life of the resting smut spores either in a dry or a wet condition.

Series of smut spores were germinated in small culture chambers and then exposed to frost for short periods and at various stages of development. The cultures were then continued under the usual conditions, but it was found that the frost had destroyed the life of the spores as soon as germination had taken place. Evidently the smut spore in its resting condition is well protected against frost, the action of which, however, becomes destructive once the protective spore wall has been ruptured by the germ tube. This experiment seems to indicate that smut spores germinating in the autumn and then experiencing low temperatures, are killed, and convey no infection. But when spores freeze, without thawing long enough to start into active life—we must remember that for this purpose a temperature of at least 41° F. is required—they may retain their vitality under such conditions unimpaired. Hence it will also be reasonable to conclude from these experiments that intermittent temperatures—at one time encouraging the germination of spores, while at others arresting further progress—afford some clue towards the solution of the phenomenon referred to.

As far as the Western grain provinces are concerned, soil infection appears to be an important matter to remember when threshing smut-infected wheat. It would be advisable under such conditions to thresh as soon after harvest as possible so as to afford the spores time for germination before the frosty weather sets in.

Grain smut causes great losses to the grower and to the country.—It is not a difficult matter to realize that a large amount of damage must be done by smut fungi throughout a great country like Canada.

The collection of reliable data for all Canada of the damage due to smut in any one year would no doubt show a very large sum of money lost to the country—and which might be saved if every grain grower would co-operate in an effort to cut off all means of dissemination of these parasitic fungi.

Many investigators have tried to estimate the damage caused by smut in other countries, and their estimates are most significant.

Oat smut, it has been estimated, causes a loss of $18,000,000 per annum in the United States. This estimate is based on an average loss of 8 per cent of the total oat crop during the years from 1890–1893. The State of Wisconsin estimates its loss due to oat smut at 17 per cent of the total harvest, or five million dollars for the year 1902. Later figures (1907) show a loss of the wheat harvest estimated at 7 per cent or two and one-half million dollars. The official reports for the State of Wash-

ington estimated the loss in wheat for the year 1902 at two and one-half million dollars.

We have from time to time examined grain fields all over the Dominion and have occasionally seen fields of considerable size badly infected by smut. Generally speaking, the farmer who has but a few acres under grain seems to exercise far less care than one who has several hundreds of acres. In some Indian reserves grain is raised, but this is generally badly smutted, indicating that no treatment of any kind is given to the grain before sowing. The more opportunities of this kind are afforded to smut fungi to grow as they like, the longer time it will require to reduce the total damage. An effort was made during two seasons to collect some data giving an approximate idea of the amount of damage done to grain crops in Canada. From the observations of two years, based on personal counts and calculation, we find an average of 6·2 per cent loss due to smut fungi in all kinds of grain.

Although the figures given (6·2 per cent) are by no means exact for the whole of Canada, or even for certain provinces, we have reason to believe that they rather underestimate the losses actually experienced. That is to say that, on the average, every grain grower in Canada loses 6·2 per cent interest on his capital.

The total loss, estimated at this percentage for the Dominion, would amount to nearly $17,000,000 per annum. The following table will show the various yields of grain, their estimated value and losses:—

Kind of grain.	Year.	Total harvest.	Value of crops.	Observed percentage destroyed by smut	Average percentage of smut.	Average losses
		Bush.	$	p.c.	p.c.	$
Wheat	1910	149,989,600	112,973,000	5 - 7	6	6,778,380
	1911	215,851,000	138,567,000	5	5	6,928,350
Oats	1910	323,449,000	114,365,000	5 - 9	7	8,005,550
	1911	348,187,000	126,812,000	6 - 9	7½	9,510,900
Barley	1910	55,147,600	21,400,300	5 - 7	6	1,284,018
	1911	40,641,000	23,004,000	4 - 7	5½	1,265,220

Total loss for two years $33,772,418
Average total loss for one year 16,886,209

The total area under grain for the year 1911 was 20,998,230 acres; considering that the loss due to smut for that year amounted to $17,704,470; the loss per individual acre would amount to $0.84 in the average. The cost of treating grain with formalin by the sprinkling method would be about 1 cent per bushel and, including labour, not more than 4 cents per acre, which would save the farmer 80 cents per acre under grain. Nevertheless, the grain-growing farmer is liable to lose this amount every year unless the treatment of grain to prevent smut is more generally practised.

II.

SPECIAL PART.

DESCRIPTION OF VARIOUS SMUT DISEASES, THEIR LIFE HISTORY AND TREATMENT.

1. 'Stinking' or 'Bunt' Smut of Wheat.

(Plate 2, Fig. b, c.)

The term 'stinking' smut, though of a somewhat striking character, is nevertheless correctly applied to this form of smut. The experienced farmer will readily discover its presence in seed wheat, even to a limited extent, by the peculiar, decidedly unpleasant odour. This odour is due to a volatile alkaloid technically known as Trimethylamine, which reminds one of the pungent odour of herring brine, from which indeed it may be chemically obtained. The odour persists for a considerable time and affords an excellent clue to the buyer of seed wheat which may be contaminated by the spores of this smut.

Stinking smut, like all the smut diseases, is due to a microscopic fungus, or rather, two distinct fungi, one a smooth-spored variety far less frequent in Canada (*Tilletia foetens* (B. & C.) Trel.), and the other far more common variety with reticulated or net-like markings on the surface of the spores (*Tilletia Tritici* (Bjerk.) Winter) (plate 8, fig. 1). Many smutted ears of wheat have been examined in this laboratory but none contained the characteristic, smooth spores of the first variety. For the purpose of this bulletin, it matters little whether stinking smut has been due to the one or the other species of fungus, for they both respond to the preventive treatment in a manner equally satisfactory.

Appearance in the field.—Where no precaution has been taken and smutty grain has been used for seed, the disease will not become noticeable until the ears have reached a certain stage of maturity, when those containing the germ of disease will appear darker green—bluish almost—and remain so much longer than the normal, uninfected ears. The affected ears will stand invariably more erect, while those containing the ripening grain—steadily increasing in weight—will slightly bend down. On pulling one if the suspicious-looking ears and examining it more closely, we find that instead of normal grains, the ear will contain bodies somewhat larger in size and decidedly plumper and shorter (plate 1, fig. e, f). This enlargement of the grain is the reason for the loose, open appearance of the ear, which will become more prominent as the ear matures, until finally the grain-like bodies are readily visible from the outside. On removing a kernel from an infested wheat ear, there will be found another external difference from the normal wheat grain in the form of a short spur at the apex of the grain (plate 1, fig. e). Upon squeezing one of these bodies between finger and thumb, the skin will burst open and a dark-coloured smeary or dusty substance, according to the stage of ripeness, will exude (plate 1, fig. f) which strongly smells of herring brine. This substance is entirely composed of the fungus spores. Under ordinary circumstances these grains, or, correctly speaking, 'smut balls,' do not burst open while in the field, and the infected ears are harvested with the sound ones.

The fungus spores.—When such wheat is subsequently threshed, a large number of the smut balls are broken, and the now free spores will infest the sound wheat grains. When badly-infected wheat is being threshed, the spores are present in such large numbers that one may often notice a black cloud issuing from the threshing machine. It is not generally realized that there may be from two to three millions of

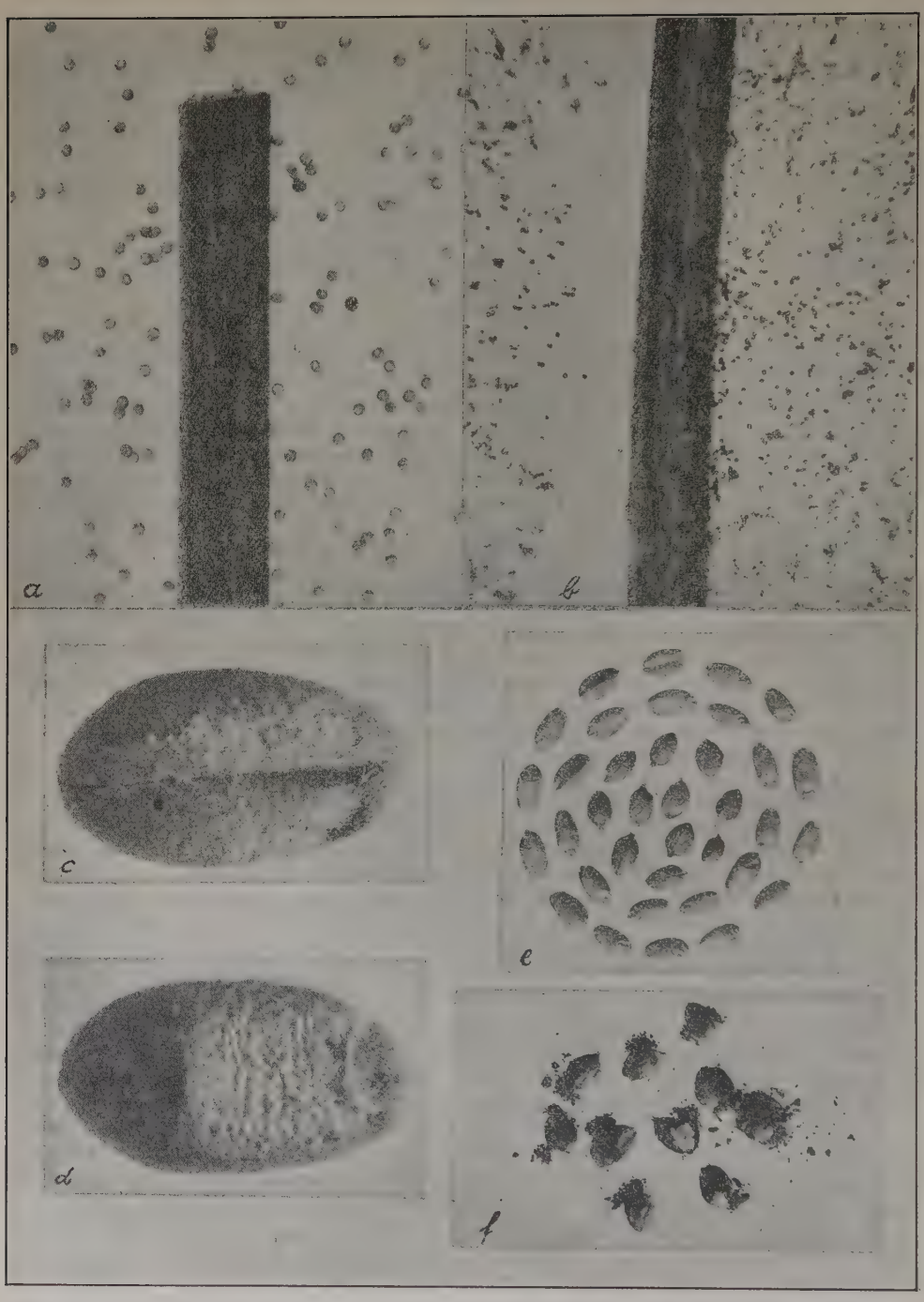


Plate 1. (a) A human hair and spores of stinking smut of wheat enlarged x 85. 8 smut spores placed side by side measure the breadth of a hair. (b) A human hair and spores of loose smut of wheat of which nineteen placed side by side would measure the breadth of a hair. (c) Lower surface of wheat grain showing "groove" and "hairy end". (d) Upper side of same grain showing surface "wrinkles" besides. Both enlarged 7. Note: if the grain of wheat were enlarged in the same manner as the human hair i.e. x 85 it would measure 23 inches lengthways; consider in comparison the smut spores. (e) The outer two rows are sound grains of wheat in the centre 11 "smut balls" showing the appendages; natural size. (f) A number of smut balls crushed; black masses consist of millions of spores.

spores in each smut ball. To comprehend the size of the spores and enable one to realize the extreme danger of sound grain becoming infected, a photograph has been taken of smut spores among which a human hair has been placed for comparison. This photograph shows the spores, as well as the hair, much enlarged, but both to the same extent, and we can now measure for ourselves that eight smut spores may be placed side by side in order to stretch across a hair (plate 1, fig. a). Once this minuteness of the single spore is comprehended, it will not be difficult to realize the extreme caution necessary to prevent them from flying about and settling upon all sorts of farm machinery, implements, tools, manure heaps, etc., from which they will be ultimately conveyed to the soil, in addition to the danger of direct infection of the soil which may take place under the conditions already discussed in the introductory chapters. Each individual spore is capable of spreading the disease.

We have already compared the fungus spore to the 'seed' of plants. Just as the seed or kernel of wheat is the agent reproducing the wheat plant, so is the fungus spore the 'seed' of the smut disease.

The spores of the stinking smut fungus are minute, round, brownish bodies with a reticulated surface—that is with fine net-like markings.

Longevity of spores.—The longevity of the stinking smut spores has been repeatedly investigated. The loose spores may retain their life for at least three years, but in the case of the unbroken smut balls, the spores within are known to have germinated some seven to eight years after production. Wheat that has been kept for eight years under suitable conditions of storage, and which at first germinated 99 per cent, showed only a germination of some 47 per cent. This makes it practically useless to store infected wheat in the hope of securing freedom from smut. The longevity of stinking smut spores is of importance to the fungus itself as it is a natural adaptation to the conditions under which the fungus plant has to live. Should the spore retain its life for a short time only—as is the case with the true loose smuts—then the possibility of reproduction would be very limited and that is contrary to nature. The purpose of the seed or the spore is to reproduce its kind, hence plants depending entirely upon this mode of reproduction have generally long-lived seeds.

The germination of the spore.—When wheat is sown which is infected with smut spores, either naturally or owing to lack of care, the spores pass through various stages of development before the wheat plant becomes infected. At first, the smut spore bursts open at any point, and a short, stout germinal tube is pushed out (plate 8, fig. B, '1'). This is known as the promycelium. The next stage is the production of a series of sickle-shaped pairs of secondary conidia arranged in a circle around the apex of the short tube (plate 8, fig. B, '2'). Each member of this 'wreath' of spores may produce another stouter, but shorter spore (plate 8, fig. B, 3), or directly, a fine hair-like tube, or the new spores may produce such tubes. These hair-like tubes of mycelium are the infection tubes. When these tubes are formed, during the period of the germination of the wheat, from the moment of the production of the first rootlet up to the time the first leaf is ready to push through its protective sheath, an infection is almost sure to follow. The infection tube pierces the young and tender tissues of the wheat seedling, and when successful in reaching the growing point, it continues to grow as the wheat grows, unnoticeable externally, until spore production, which takes place in the wheat ear.

It has been previously stated that the conditions of temperature prevailing at the time of the germination of wheat and spore may determine whether an attack will result or not. In this connection it may be mentioned that occasionally there may be found only one or more ears attacked by the fungus, while others of the same plant may be quite sound. This fact may be explained as follows:—

Each ear of wheat is produced in a separate shoot with a definite and individual growing point. Generally speaking, the fungus attacks the various growing points at an early age, but when, for some reason or other, the first ears have

escaped infection, a second growth which may result may not have succeeded in making its escape, and, the growing points being invaded by the fungus, will carry the infection until ultimately producing infected ears. Besides, in the development of plant diseases, so much depends upon the even balance of conditions or 'constitution' of the host plant itself and the vigour of the fungus. The stronger will surpass the weaker element. In this way it would be reasonable to expect occasionally that one plant may produce sound and unsound ears, or sound, partly, and wholly diseased grains in the same ear, which as we have observed does occur (plate 2, fig. c).

Notwithstanding the statement that the smut fungus, while growing within the plant cells, produces no visible ill-effects until the ear appears, yet the fungus may be feebly present in the cells, and in some instances not succeed in reaching the ear, when that ear will escape infection but will show a poorer quality. Where it is desired to produce a good strain of wheat, it would be unwise to start with seed grain known to result from an infected crop, however successful the treatment for smut may be, for an imperfectly-developed grain possesses a reduced energy of germination, and we know that vigour of germination and the strength of the young plant are important factors in effecting an escape from infection. It is generally accepted that plump, well-developed grain produces the best plants, and grain of low vital energy yields less well, besides being liable to infection to a much higher degree.

Stinking smut confined to wheat.—Microscopically and biologically, stinking smut of wheat is quite different from other grain smuts. Each kind of grain has its particular parasites which cannot affect any other plant. When smut spores of wheat are sown with oats or barley, or *vice versa,* these plants will not become infected. If this were the case, their treatment or control would be uniform throughout, but we have already explained the different methods of infection that exist in various smut forms and which require different modes of treatment.

THE CONTROL OF STINKING SMUT.

Is it advisable to treat all wheat before sowing?—As it is decidedly doubtful if there is any wheat sold in this country originally free from infection, or, if originally free, kept in such condition, it appears advisable to make smut treatment just as much a part of one's routine as preparing the land for sowing. Though there cannot be any doubt that some wheat is more affected than others even when only a limited infection exists, it is very desirable to prevent its increase by treating it. Besides, there is much danger from the neglect of treatment owing to the fact that there are a number of fungi producing a more or less serious discolouration of the grain. We have recently devoted considerable attention to the cause of the various discolourations often found on wheat grains, and particularly abundant after wet seasons or on wheat from low-lying ground. There are fungi like *Fusarium* and *Septoria* which may cause destruction of the plant, or at any rate affect the yield and quality of grain, and other more superficial fungi like *Cladosporium, Heterosporium, Epicoccum, Hormodendron,* etc., which cause spotting of the surface of the grain. The nature of these fungi is as yet little understood, but they are, no doubt, often responsible for the decay of the grain when sown. It is reasonable to believe that seed treatment as recommended for smut would also prevent any injury from fungi of this nature, hence we strongly recommend that wheat and other grain be always treated before sowing. For experimental purposes one may select small samples of wheat which are reasonably clean, but this is not yet possible under general conditions of farming.

The treatment for the prevention of smut diseases, propagated by the spores of various fungi adhering to the seed, is directed against the destruction of these. There are two main methods of treatment generally practised, each of which has peculiar advantages and disadvantages over the other, but, nowadays, where scarcity of farm labour is an important consideration, that which requires the less work is to be preferred. The two methods referred to are known as 'steeping or pickling' and 'sprinkling' the grain with certain solutions.

Before dealing with smut treatment, it may be mentioned that washing grain thoroughly in running water, in order to get rid of the smut spores, is practised with satisfactory results, providing it is done properly and that there is a good water supply available. The grain may be placed in barrels for this purpose and the water allowed to flow in from below; it will soon rise to the top and overflow. By vigorous agitation of the grain with a stick, the smut balls will rise to the top and the spores will be carried away. Seed grain of special value may be treated quite satisfactorily in this manner.

For some years chemical solutions have been used with great success; partly because the water question may be a serious one, partly because the time required is less. Before treating any wheat, it should be remembered that, occasionally, unbroken smut balls may be contained in the grain; these will eventually break, often at the least desirable moment, i.e., after treatment, and of course re-infect the grain with smut spores. No solution has been found to penetrate the unbroken smut balls in the short time during which they are subjected to treatment, hence the spores inside are not killed.

The fanning mill will remove smut balls very completely from the wheat, and owing to the danger pointed out, any wheat containing smut balls should be sent to the mill before treating—if none is available at the farm. Should, however, any smut balls appear on the surface of the solution when grain is being treated, it is necessary to remove them quickly. The smut balls are much lighter than the grain, and will rise to the surface when the latter is vigorously and repeatedly stirred. We have found, however, that the time of treatment given to wheat or other grain is far too short to permit the removal of all smut balls rising to the surface. Even when prepared and working quickly, we have not succeeded in scooping off all smut balls, that came to the top during treatment, under 10–15 minutes. This long exposure of grain will seriously affect the germination.

The chemicals now universally employed for treating grain for smut are sulphate of copper or bluestone and formalin.

Bluestone is sold in the form of crystals or as a powder; the former, while dissolving considerably more slowly, has the advantage of showing plainly any signs of decomposition by a brownish discolouration. The crushed crystals (or bluestone powder) appear generally in the form of a coarse bluish-green salt. The best bluestone to use is in the form of bright blue crystals. Bluestone quickly corrodes iron. For this reason use only wooden pails, barrels or tanks. Note particularly that grain treated with bluestone is highly poisonous to live stock; it should only be used for seed purposes, and any that may be left over should be deeply buried.

Formalin is a solution of formaldehyde gas in water, and when buying it, it should be of not less than 40 per cent strength. This is the usual strength. The stock solution should always be kept in a well-stoppered bottle. Formalin is nowadays preferred, partly because of the greater facility in preparing the proper solution, and partly because grain, treated with formalin, when once thoroughly dry, is not injurious to live stock. Formalin appears to be difficult to obtain at short notice in some localities. The bluestone treatment is referred to here mainly for this reason. Those who intend using formalin would do well to secure their supply in good time from a reliable chemist, so that it may be available when required.

Either of these chemicals, in solution, may be employed for 'steeping' or for 'sprinkling.'

Steeping in sulphate of copper solution.—Secure a wooden barrel of convenient size and dissolve 5 pounds of bluestone in 50 Imperial gallons of water. Bluestone crystals take considerable time to dissolve. The solution is not ready for use until this chemical is entirely dissolved. Time may be saved by tying the 5 pounds of bluestone crystals into a wide-meshed piece of sacking or bag and suspending this over night in the necessary quantity of water. Hot water dissolves the crystals far more readily. For this purpose, the quantity of bluestone may be heated in water

until dissolved and then be poured into the barrel with as much less water as has been used for dissolving it.

When the solution is ready for use, fill two barrels half full with it and dip into each a bag containing the wheat intended for treatment. The solution must cover the grain about three or four inches. Lift the bag several times up and down in the solution to drive out the air between the grains and allow it to remain for exactly three minutes, but not for a longer or shorter period. During this time the grain will be evenly wetted and should then be taken out, drained and spread out in a thin layer to dry.

Steeping in formalin.—Solution required: 1 pound of formalin of 40 per cent strength in 40 Imperial gallons of water. Proceed in the same manner as described above, but allow five minutes for immersion. Drain and spread out to dry.

Sprinkling method with bluestone.—This method is far less laborious than steeping, and, if carefully carried out, just as effective.

Solution required: 1 pound of bluestone dissolved in 10 Imperial gallons of water. For this purpose the whole quantity of grain should be piled in a heap on the clean barn floor, and the solution should be sprinkled on this heap by means of an ordinary sprinkling can or a broom. Then begin shovelling over the wheat as quickly as possible, forming another heap, in the manner of mixing cement for instance, and back again until every grain is evenly wetted. More solution may be gently added if it is found that many grains are left dry. The wheat should not be drenched but evenly moistened. When completed, spread out to dry.

Formalin for sprinkling.—In sprinkling with formalin use 1 pound of formalin in 40 Imperial gallons of water and proceed in the same manner as described for sprinkling with sulphate of copper. Leave the pile for two or three hours and cover with sacks, then spread out to dry. (*Note.*—40 gallons of solution will 'sprinkle' about 40 bushels of grain.)

GENERAL PRECAUTIONS AND HINTS.

Wheat which is badly infected with smut spores requires careful handling, when pouring it on to the barn floor or when handling it at all. The spores will blow away like dust and settle everywhere when such wheat has been moved. Hence the bags, tools or other implements are likely to be contaminated, and, when used for treated wheat, will carry infection. As long as the wheat is still wet, such contamination is of little moment, but when dry it is often re-infected in this manner, and the efficiency of treatment is often regarded with suspicion if, notwithstanding the treatment given, smut does appear in the new crop. Machines, tools and bags may be rendered quite free from smut spores by washing the former or soaking the latter in any of the solution used for treatment. The floor of the barn should be swept before treatment of grain is begun, but not while the treated grain is kept in it. After each separate treatment, wash down the floor of the barn with the solution used. Under no circumstances return the treated grain into the old bags which contained it before treatment unless they have been soaked in bluestone or formalin solution and dried.

Solutions do not lose strength.—The bluestone solution remains of the same strength as when first prepared and may be used over and over again. Add more solution if the quantity is reduced by use.

The formalin solution rather increases in strength when kept for a time; the water evaporates more quickly than the gas.

Treating large quantities—formalin preferred.—In the Western provinces or elsewhere, where large quantities of wheat are required to be treated, the sprinkling method, using the formalin solution, will be found more convenient, if it is carried out in the grain wagon. For this purpose pile the grain up towards one end of the

wagon and sprinkle it, afterwards shovelling it to the other end and to and fro until the grain is evenly moistened. The grain can remain in the wagon over night covered with bags when it will be dry enough to pass through the seed drill by next morning.

'Smut machines.'—Special machines have been devised to facilitate the treatment of grain for smut. Some of them are of greater value than others for the purpose, but in all it will be necessary to adjust the operations carefully or the grain will be treated for too long or too short a time to yield proper results. Such machines might be of great value if the grain elevators would install them and carry out the treatment for smut of grain which the farmers may bring to them. At any rate the question of a suitable machine only concerns private individuals who have to treat very large quantities.

Injuries to the vitality of grain following treatment.—It is important to realize that if treated grain, while still wet, is exposed to frost, the germination will seriously suffer. In some experiments undertaken with a large number of varieties of grain of all kinds, it was clearly demonstrated that the action of frost is decidedly destructive, more so with some varieties than with others. On wheat treated and thereafter exposed to frost over night—the temperature going down to 10 degrees of frost (22° F.)—it was found by subsequent germination tests that all varieties had lost over one-third of their power of germination. The highest germination was observed in the variety 'Huron,' 62 per cent, and the lowest in 'Turkey Red,' 19 per cent. In oats, 'Thousand Dollar' germinated highest with 49 per cent, and 'Improved Ligowo' with 26 per cent. Barley seemed to suffer most of all. 'Odessa' was the highest with 21 per cent and 'Hannchen' showed no germination at all. This clearly shows the necessity of guarding against frost. When once dry, the grain suffers no injury from cold of the same temperature.

The treatment with chemicals, while very effective in controlling smut, exerts an injurious influence on the grain. While the injury is reduced to a minimum by careful treatment, yet carelessness in preparing the solution or in keeping to the time recommended will often result in great losses.

In this connection, it may be stated that formalin treatment has been known to exert a very curious influence upon wheat kept in storage after treatment. Dr. C. E. Saunders, Dominion Cerealist, kindly furnished me with figures on this point which are very instructive. He found that wheat originally germinating 75 per cent had lost its life completely when retested one year later. A sample of oats originally germinating 62 per cent and one of barley with 71 per cent, germinated a year after treatment 2 per cent and 3 per cent, respectively.

Dr. Saunders further states: 'Unfortunately, it does not appear that any tests of these samples were made immediately after treatment. We know, however, from other experience with formaldehyde of that strength (36 ounces formaldehyde in 40 gallons of water) that the germination would not have been reduced immediately to any such figures as those found a year after the treatment. The worst case in wheat which I have been able to find shows that the sample germinating 83 per cent was reduced to 40 per cent by treatment with formaldehyde of the strength used in the above tests. In other cases the reduction in vitality was considerably less.'

Mr. Frank T. Shutt, M.A., Dominion Chemist, who deserves much credit for a considerable amount of valuable information on the question of the treatment of grain for smut, reports on two samples of wheat treated with 18 ounces formaldehyde to 40 gallons of water and soaked for five minutes. The vitality of these after treatment was shown to be 70 and 86 per cent. A year later they germinated only 9 per cent and 14 per cent, respectively.

The observations of these investigators are of great interest. The injurious influence of formalin is known to be specially severe on grain of low vitality. In the cases quoted by Dr. Saunders we are inclined to attribute the result to this fact, as wheat, originally germinating, as stated by him, 75 per cent, oats 62 per cent, and barley 71 per cent, cannot be considered of high vitality.

Dr. McAlpine, the Plant Pathologist of the Government of Australia, reports that wheat treated with 1 pound formalin in 40 gallons of water loses its power of germination, to some extent at least, after being kept a few days; that this effect is cumulative, for a time at least, but gradually disappears after, say, four to five weeks.

The injurious action of bluestone on the vitality of grain is generally established, and if the treatment as recommended is not carefully carried out, or if there exists any doubt about it at all, it is advisable to sprinkle the grain, after treatment with bluestone, with lime-water (1 pound of lime to 10 gallons of water strained through cheese-cloth), which will greatly reduce any injurious action.

2. Loose Smut of Wheat.

(Plate 2, Fig. d.)

Appearance in field.—The observant farmer will be acquainted with another 'smut' disease in wheat very different from stinking smut. This kind of smut becomes noticeable in the field at the time when the ears are being formed, when some will be found covered with a black, sooty powder, which is, when ripe, readily shaken off on touching. At a later stage, only the central axis of the ear will be left, and no grain will be produced. This smut is the loose smut of wheat, and is readily distinguished from stinking smut by the distinctly black spore powder which is produced 'loosely,' i.e., without any covering, as is the case with smut balls in stinking smut.

Related, but biologically distinct from loose smuts of barley.—The loose smut of wheat is closely related to loose smut of barley. Though very much alike, however, in appearance, the two fungi causing the loose smut diseases in wheat and barley are as distinct from each other as the two plants on which they grow. It may be said here that only comparatively recently was it found that all the various forms of smut in grain are quite different from each other. Cross inoculations, i.e., infecting, for instance, a wheat plant with smut from barley, or an oat plant with smut of wheat, clearly proved this fact, as under no circumstances was it possible to produce a smut disease with spores taken from a different host plant. This behaviour gave rise to very careful researches into the life history of the smut fungi which afforded ample confirmation of this experience.

Although so much alike to the naked eye, and somewhat alike when viewed under the microscope, the spores of the various smut fungi produce plants as widely different, biologically, as the plants of cabbage, cauliflower, rape, turnip and other cruciferous plants, which have seeds so much alike that they can hardly be distinguished, except by certain microscopical features.

A study of the life history of the loose smut of wheat will clearly reveal its nature.

Life History of Loose Smut of Wheat.

Loose smut of wheat is due to a fungus technically known as *Ustilago Tritici* (Pers.) Rostr. When harvesting a field of grain in which we have noticed a number of ears affected with loose smut (plate 2, fig. d), we will be surprised to find no evidence of the disease except the dry central axis, which was formerly densely covered with the black spore powder. It is indeed a fact that most of the smut spores have disappeared. The absence of spores is somewhat unfortunate because it is likely to cause indifference. Where have these spores disappeared to? The question is very simply answered: the wind, waving the grain about, blew off the loose spore powder. Millions of spores that are produced in each head will be carried by the wind and will settle upon all parts of the neighbouring plants, upon the soil and wherever there is the slightest degree of moisture which will hold the spores.

Spores ripe before wheat is in flower.—On carefully looking into the subject, we will notice that the smut spore powder is produced before, or just at the very time,

Plate 2. The smuts of wheat. (a) A sound ear, lower half with hulls removed showing the sound grains in place. (b) Characteristic "spread out" appearance of wheat ear infected with stinking smut; note: four smut balls showing where sound grains should have been formed. (c) Ear partly affected with stinking smut; note the cross indicates a perfectly sound wheat grain. Below this all grains are more or less completely infected with smut. (d.d.) Two ears of wheat destroyed by loose smut, no grains are formed. Picked at the time of flowering. All figs. slightly above natural size.

the normal or sound ears are in flower. As soon as the flowering period is over the first crop of smut spores is dispersed. However, a second and even a third crop of infected ears may be produced from an infected wheat plant, which will produce ripe spores at the same time as the healthy plant produces its second or third crop of ears. Again just after the flowering period of these secondary ears is over, the smut spores which have been produced have disappeared.

Significance of the time at which spores ripen.—This fact of the dispersal of the spores taking place at the time of flowering of the wheat plant is no mere coincidence, it is the most important factor in the whole life history of the fungi producing loose smut in wheat and barley.

After many years of research on this problem, the repeated failure of all investigators to reproduce loose smut in wheat by spore infection of the young wheat plant, which so readily takes place in stinking smut, seemed to indicate that the solution of this question would lie in a different direction. Naturally, it was at first expected that the spores of loose smut would adhere to the wheat grain and germinate as the seed grew, or that the spores no doubt present in large numbers in the soil would retain their germination over winter until the new wheat was sown. The life history of the stinking smut, the spores of which grow so readily in artificial cultures even years after harvest, of course influenced the opinions advanced. But the spores of the loose smut fungus persistently refused to germinate, and, indeed, as was shown later on, they retained their vitality for a few months only.

Flower infection takes place.—It was then that the independent researches of Brefeld and Hecke as late as 1903-1904 conclusively proved that the perpetuation of the loose smut diseases took place through flower infection and not in any other way, confirming in this manner the results of the earlier experiments carried on by Frank Maddox in Tasmania in 1895 and later, viz., 'that putting smut germs on the ovary about the time the pollen is ripe will always reproduce the disease the following year.' Thus the mysterious connection existing between the production of ripe smut spores just at the time of the production of the flower in wheat was explained.

The flower of the wheat plant.—To thoroughly comprehend the following chapters in the life history of this smut, let us briefly study the flower of the wheat (see Plate 3, figs. 1-5). Towards the end of June, or in July in many parts of Canada, the young ear of the wheat will show a large number of fine, yellowish appendages protruding from the upper part of the scales which later on enclose the mature grain (plate 3, fig. 1). These are the stamens of the wheat-flower with their large anther cells containing the pollen or male reproductive bodies (plate 3, figs. 5, c, d). On removing dexterously the outer glume and the pale, we discover the remaining parts of the flower, consisting of two thin, fringed scales, and the pistil with two feathery styles (plate 3, fig. 3; b, e, f). When the pollen in the anthers is ripe, these burst and the pollen grains (plate 3, fig. 5) are discharged and caught by the feathery styles where they are held fast (plate 3, fig. 4). Here they soon begin to germinate and push through the style into the interior the pollen tubes which ultimately reach the ovary, when fertilization of the ovule is effected.

Germination of smut spores.—During this period the production and dispersal of the ripe smut spores take place. The spore of the loose smut of wheat is considerably smaller than that of the stinking smut (plate 1, fig. b). On germinating in suitable media we find that its development differs greatly from that of other smut spores with the exception of loose smut of barley. We find no secondary spores but simply germ tubes, however far the artificial culture may be carried (plate 8, fig. c; 1-3). This mode of germination is in accordance with its mode of reproduction. In cultures the life of the loose smut spore of wheat soon exhausts itself, while the stinking smut may be carried on indefinitely. This observation confirms the statement regarding the brief life of the spore, which indeed is similar to the life of the pollen grain.

Plate 3. Figs. 1—5 the flower of wheat; figs. 6—9 flower infection and position of th e germ of smut in the grain Fig. 1. An ear of wheat in flower; (a) anthers (natural size). 2). Single spikel e t of wheat ear; (a) anthers (3). Female organs of flower, (b) the feathery st) . . . ovary ; (f) ovule. (4). Part of style (b) covered with pollen grains (c). 5. Pollen grains (c) showing germination tube (d). 6. Section of wheat grain showing the young plant (h). 7. The young plant removed from the wheat grain, much enlarged. (g) the "scutellum" or disk through which the young plant absorbs its food from the body of the grain, (h) the growing point, (i) the primary root, (j) its sheath, (k) secondary root, (l) black lines showing position of mycelium of loose smut fungus as found in the grain. 8. Part of the style (b) showing a loose smut spore (n) pushing mycelial tube (o) into the tissues. 9. Microscopical preparation showing mycelial masses of fungus within the tissues of the grain (m). (Figs. 1—6 from "The life of the wheat plant." Fig. after Hecke. Figs. 8, 9 after Lang.)

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Analogy of smut spores and pollen grains.—Pollen grains which do not reach the style but fall to the earth or elsewhere soon succumb, because their only function is the fertilization of the ovule. The smut spore likewise succumbs very quickly if it does not reach the style of the wheat flower. Having been successful in reaching that spot necessary for its perpetuation, it germinates in a manner similar to but not necessarily identical with, that of a pollen grain, pushing its germinal tube first through the fine hairs of the feathery style (plate 3, fig. 8), then through the style itself, and finally, into the ovule, where its progress is arrested for the time being. Its germination is only by means of the germ tubes which it sends into the forming seed, causing a direct infection of the young grain. There is no need for secondary spores, nor any necessity for a prolonged life in the spore stage, inasmuch as the fungus lies well protected within the grain. To perpetuate its kind, the spore must reach the flower of the wheat. If the period of flowering is over the smut spore must die.

Smut fungus lives in the grain.—During the development of the grain the smut fungus now within it makes but little growth, but remains alive, though quite dormant like the seed itself. The filaments or mycelium of the fungus were first successfully demonstrated by Hecke in the tissues of the young plant. Later in 1910 Wilhelm Lang provided convincing evidence of the presence of the germ within the grain (plate 3, fig. 9). Every infected grain will give rise to an infected wheat plant, the ears of which will contain a new crop of spores, and thus a new life cycle will begin.

Loose smut cannot be controlled by formalin or bluestone.—From the above description of the life history, it will be readily understood that this smut cannot be controlled in the manner prescribed for stinking smut. Though there may be hundreds of thousands of spores present on the surface of the wheat grains or in the soil, we know that they are dead, or at any rate need not be taken into consideration as carriers of infection. We also know that the germ of the disease lurks within the embryo of the grain, without revealing its presence by any external symptom. Even the recognition of the germ within the embryo is a matter of difficult technique. But all the same the disease is present and will appear, with hardly any exception, in the plant growing from such seed.

Remove whole plant if affected.—However often a farmer may pull out diseased ears as they appear, every new shoot will produce new smutted heads, hence the whole plant should be destroyed immediately the disease becomes noticeable. It will also be realized that the prevention of this kind of smut must be, if at all possible, along very different lines from that of stinking smut.

Successful treatment regarded with doubt.—The opinion expressed by Brefeld that, owing to the presence of the smut fungus in the grain, it would not be possible to kill the smut fungus without destroying the germination of the wheat itself, was shared by a large number of other investigators.

Discovery of hot water treatment.—However, when the question regarding the control of smut diseases had received the attention of a large number of investigators, who, at that early date, were still in the dark about the life history of the loose smuts, one of them, Mr. J. L. Jensen, of Denmark, discovered in 1887 that hot water of certain temperatures would destroy the life of smut spores, especially of those diseases propagated by spores adhering to the surface of grain, without injuring to any marked extent the germination of the grain itself. At first, the method was employed simply against stinking smut of wheat, oat smut, and others of the same kind. But the method was ultimately improved, when it was found that by carefully treating grain which contained the loose smut germ within its tissues, control of the disease was obtained, and, at the present stage of our knowledge, it would seem the only one efficient in checking the recurrence of loose smuts.

Preliminary remarks on hot water treatment.—The hot water treatment consists simply in the immersion of the infected seed grain for about ten minutes in water kept during this time at a constant temperature not below 122° F. and not above 126° F.

Will cause loss of germination.—It is also claimed and proved by experience that from 6–10 per cent of good sound grain will be injured in the treatment, while seed with a low power of germination at the beginning will lose far more of its germinating power.

Even though considering an average loss of 8 per cent from hot water treatment as unavoidable, this could easily be made up by an increase of 8 per cent in the rate of sowing. In one bushel and a half—the usual rate of sowing per acre—a little over 7 pounds would have to be added, which would mean the very slight increase in cost of 7–8 cents, whereas a loss of 5 per cent from smut in the field would really amount to a loss of $1.25 per acre or so.

Co-operative work in hot water treatment.—In Denmark smut-treating plants have been installed during the past ten years to a considerable extent in the creamery and brewing establishments, where the grain of the farmers in the locality is subjected to the hot water treatment at a small cost, and in which plants there may be treated in ten hours as much as 250 bushels (certainly sufficient for farms of considerable size). Notwithstanding such co-operative arrangements, which would make hot water treatment, especially of large quantities of wheat, more feasible, we cannot conceive of its being made the general practice in Canada, especially in the West, where the problem of manual labour and even the water problem itself will offer most serious objections, at any rate for some years to come.

But we strongly urge the farmers not to be negligent on this account, but follow strictly the suggestions made along the following lines, by which it is hoped that the problem of loose smut of wheat may be eventually solved. Begin slowly and persist in your efforts, and loose smut will cause very little damage. Dr. C. E. Saunders, in conversation on the subject, stated that some years ago loose smut was a factor of considerable moment in his Ottawa experimental plots, but at the present time it only occurred in a negligible percentage, and he hoped that it would disappear entirely. This result is largely due to the untiring efforts of Dr. Saunders to control this smut by every possible precaution.

Raising of one's own seed supply from pure seed.—The solution of this problem lies in the practice of growing one's own seed grain, starting with clean seed grain or such as has been treated with hot water. The difficulty of the hot water treatment will be largely avoided and success in prevention of loose smut proportionally increased if the farmer will start rightly.

Method for securing smut-free seed grain.—The first year he may begin by securing, say, three-quarters of a bushel of the very best wheat of that variety which has given the greatest satisfaction in his neighbourhood. This small quantity is easily subjected to hot water treatment in the way to be described presently, and it will suffice to sow one-half acre. It is important that this half-acre plot should be far enough removed from any other wheat field to prevent smut spores from being blown over from an infected field. From the observations recorded in a former chapter, it would seem that 500 yards away from other wheat would prove a safe location for the 'seed grain' plot. It may be difficult or impossible in some typical wheat-growing centres to remove the seed plot thus far from other growing wheat. We would recommend as an alternative to surround this plot with a shelter belt of trees or shrubs. In the West, the Siberian pea tree would provide a very suitable shelter. These belts will very effectively eliminate the danger from outside infection.

If the treatment has been successful, and that will depend upon the amount of care with which it has been practised, the smut should be entirely absent from this

one-half acre plot. It would be advisable, however, to carefully examine the plot before flowering time and remove at once every plant, roots and all, of wheat that shows a suspicion of smut. This removal of affected plants may safely be carried on before the spores are ripe, and this is the most correct time to remove them, else the very act of gathering ears with ripe spores will scatter them wholesale, and the walking through the plot with a handful of gathered smutty heads will be the worst method of infecting the flowering grain, which would otherwise have remained free from smut. This should be well borne in mind. As soon as the spores are ripe infection has taken place to a large extent, and removing the plants carelessly will make it worse. It is advisable to provide paper bags and carefully draw the heads of an affected plant together, invert the bags over them, and then cut off the whole number of heads. The plant should then also be pulled up.

The yield of this seed plot should be quite free from smut. Under ordinary conditions it would yield 10–15 bushels of grain or sufficient to sow 6 to 10 acres in the next year, the yield of which would provide seed grain for a considerable area.

It is just as easy to treat five bushels of wheat as three-quarters of a bushel, and, where the experimental treatment has proved successful, the farmer might well start with five bushels of treated wheat.

The seed plot should be maintained each year; by paying additional attention to the quality of the strain in selecting one's wheat for the 'first seed plot' the benefit from the trouble—if the care exercised has any right to this name—would be largely increased.

Grain subjected to hot water treatment is free from all kinds of smut.—It may be pointed out here that any kind of grain treated with hot water requires no separate treatment for other kinds of smut, as the hot water will destroy the spores of all smut diseases. We do not consider it necessary to treat with hot water seed grain obtained from the seed plot or even that produced under field conditions under the circumstances described, unless, of course, loose smut has become re-established, when the hot water treatment should be resorted to again. We do recommend, however, to treat the wheat with bluestone or formalin for the other kinds of smut, if it has not been subjected to the hot water treatment.

Stinking smut, it should be borne in mind, may be introduced by a threshing machine which has been previously employed in threshing wheat infected by this kind of smut.

The hot water treatment for loose smut.—We have already referred to the great power of resistance to frost possessed by stinking smut spores; it is an established fact that resting or inactive organs or parts of plants like seeds, tubers, fungus spores, etc., are much less susceptible to external influences than the growing plant, hence the death of germinating spores on exposure to frost.

Reasons for the success of hot water treatment.—Dr. Appel, of the Imperial Biological Institute for Forestry and Agriculture, Berlin, Germany, who has largely contributed to our knowledge of the control of loose smut, points out that the spores of loose smut will germinate in artificial media after only four hours, when kept at a temperature of 77° F. He concluded that the mycelium resting in the wheat germ might be stimulated into activity in the same brief period of time by immersing the infected grains in water of this temperature. That is to say, the resting fungus may be awakened from its condition of rest before the wheat grain itself would be influenced in a like manner (i.e., start to germinate), which may be considered out of the question within four hours. Hence it was reasonable to believe that the action of water of a higher temperature would destroy the germ of disease, now in a more vulnerable state, without exerting too injurious an influence upon the life of the grain. We have already pointed out that injury is actually caused to a more or less large, but nevertheless negligible, extent, but we have also shown that loose smut is very satisfactorily controlled by these means, and that it is at present the only method known.

Jensen's original hot water method has been considerably modified owing to the advanced researches, particularly of Appel, who demonstrated that soaking the grain previous to the real hot water application is of decided advantage. We have explained the scientific principles of such treatment, and will quote some interesting figures given by Dr. Appel* which show the results very convincingly.

It was first necessary to demonstrate whether previous soaking followed by the main treatment would reduce the smut disease and what temperature would be the most advantageous. Wheat was soaked for four hours, or the time which it took the spores to germinate at 77° F. Various temperatures were used; the wheat was then treated with hot water in the usual way, with the following result:—

Temperature of water of preliminary soaking..	34°F.	48°F.	64°F.	86°F.
Percentage of smut in field plot noted..	4·6%	3·1%	1·1%	0%

The percentage of smut in an untreated check plot was 4·9%.

In addition, Dr. Appel investigated the question of the length of time necessary or most advantageous for the preliminary treatment. Some of the same wheat served the purpose as used in the first experiment.

Length of preliminary treatment...	2 hours.	4 hours.	6 hours.
Percentage of smut in field plot noted..	2·7%	1·1%	0%

In this experiment the temperature of the water was 64° F.

The conclusion drawn from the above experiments, of which a considerable number were performed, is as follows:—

'It is thus shown that a reliable method for the control of loose smut of wheat (and barley) has been discovered, viz., soaking the grain for a period of from 4 to 6 hours in water of a temperature from 68° F. to 86° F., followed by a treatment with hot water at a temperature not below 122° F. and not above 129° F.'

The next point to consider is the length of time required for the 'main' treatment, i.e., the exposure to the hot water. This will depend to some extent upon the facilities for maintaining the correct temperatures, but the general rule is 10 minutes at an even temperature of 124°–125° F.

We have endeavoured to explain in the foregoing lines the reason for the various manipulations, believing that the successful control of any enemy of plant life depends largely upon a thorough acquaintance with its nature or life history.

The farmer will immediately realize that there are some serious objections from the practical point of view to this treatment, but then it must not be forgotten that at the present time this method is the only one known to control loose smut. After all, the apparent difficulties may be largely overcome by systematic work, and, by the exercise of care, this treatment will give highly satisfactory results. We will now carefully describe the carrying out of this treatment.

SIMPLE METHOD FOR HOT WATER TREATMENT.

(*a*) PRELIMINARY TREATMENT (SOAKING).

Apparatus required.—1. One reliable thermometer; the ordinary bath-tub or room thermometer is very undesirable for this purpose, but a good dairy thermometer will serve the purpose well.

2. One large wooden barrel or any kind of metal tank or large vat.

3. A number of good strong grain bags which will allow the water to pass through rapidly.

4. Some kind of stove, boiler or fireplace to heat the water.

* Otto Appel, Theorie & Praxis der Bekämpfung, &c., Ber. D. Bot. Ges., Vol. 27, Heft 10, 1909.

Procedure.—1. Heat water in the boiler to almost boiling. Pour into large barrel or tank (before proceeding further refill the boiler with water) and add slowly, with vigorous stirring, cold water until the temperature is exactly 86° F. Unless the water is well stirred the correct temperature cannot be taken. Read the temperature without removing the thermometer from the water. The mercury bulb should always remain submerged when taking the reading.

2. Fill grain bags three-quarters full with the grain to be treated and tie them up loosely. Immerse into barrel with water at 86° F., move bag several times up and down, which will force out the air quickly. Take care the water covers the grain at least several inches. Allow the grain to remain in this water four hours.

NOTE.—The temperature of the water will become lower when the grain is introduced. Should it cool down too quickly, i.e., sink below 68° F., allow five hours for soaking.

Treat the grain, if possible, in a heated room to prevent the rapid sinking of the temperature. By placing the barrel or tank in a large wooden box, tightly packed with wood shavings, hay or straw all around, and covering it with a lid, the temperature remains fairly constant for four hours, once the grain has assumed the temperature of the water. One ordinary barrel will treat about one bushel of grain or a little more. Use two or three barrels or one of larger size if more grain is to be treated. The larger the barrel and the greater the volume of water, the more easily will the temperature be kept constant.

(*b*) MAIN TREATMENT WITH WATER.

Additional requirements.—Two large barrels or vats, each capable of holding from two to three bags of grain. A water can with a sprinkler attached.

Procedure.—Into the first barrel pour a quantity of nearly boiling water and add cold water slowly until the temperature is accurately 112° F. (Fill up the boiler immediately, as more water will be required in a short while). Then take out the grain from the 'soaking' barrel and place in this one. Move several times up and down and allow to remain for 15 to 20 minutes.

Meanwhile prepare the other barrel; pour in hot water as near boiling as possible, add cold water slowly, with stirring, until the temperature is exactly 129° F. Then take the bags out of the second barrel (the one with the water at 112° F.) and place in the barrel with water at 129° F. This will cause the temperature to sink to some extent; should it sink below 122° F. fill the sprinkling can with hot water and sprinkle into the barrel, but under no circumstanaces upon the grain or the bags containing it. When, however, the bags are well covered with water, at least four or five inches, the hot water may be safely added. To mix it with the whole contents lift the bags up and down, or move them around the barrel. The grain must remain for exactly ten minutes in this last barrel, during which time the water should be maintained evenly at a temperature from 124°–127° F. It should never sink below 122° F. nor be hotter than 129° F. The former will be ineffectual in killing the smut, the latter will cause unnecessary damage to the grain.

(*c*) DRYING THE TREATED GRAIN.

Of all the difficulties of this hot water treatment, the complaints about the trouble in drying the grain after treatment exceed all others. When taking the bags out allow them to drain thoroughly. On sunny days the grain may be spread out in a thin layer in the open air, when shovelling or moving it with a wooden rake will render it sufficiently dry for sowing in a few hours. It is necessary t emphasize the caution that should be taken as regards the reinfection of treated grain, which subject has been fully dealt with under the chapter on stinking smut. When the temperature is below freezing, or on dull or rainy days, the grain should be spread out in a thin layer on the clean, dry floor of the barn. It is most important to keep

on shovelling the grain over to allow of air being mixed with it, when it will dry far more quickly. Besides, grain which is left lying untouched is liable to become mouldy, and this will destroy its germination. At times, especially on dull days, it is advisable to chill the grain by placing the bags for a minute or two in cold water, moving the bags several times up and down before spreading it out for drying. This has been found of advantage, especially when barley is being treated. In rare cases, grain has begun to sprout while spread out for drying. This causes no harm whatever, providing the grain is sown before it is absolutely dry. In the laboratory we have found that grain that has sprouted and is allowed to get fairly dry will revive completely when sown without much delay and grow just as well as untreated seed.

FURTHER REMARKS.

Danish co-operative method for hot water treatment.—In Denmark, where the hot water treatment is probably most widely practised, arrangements have been made with breweries and creameries in which steam and a permanent water supply are available. The farmers bring their grain to such centres and have it treated, but must remove it in a wet condition and dry it at home.

Special machines used in Germany.—On the continent of Europe, especially in Germany, there are machines in use to a limited extent for the hot water treatment of grain, some of which give great satisfaction. Dr. Appel, for instance, has designed a machine of this kind which appears to have never been surpassed in efficiency and simplicity. Perhaps at some future time such machines may be found necessary in Canada, and anyone who desires more detailed information concerning the Danish co-operative treatment of grain or a description of Dr. Appel's machine, which it is not necessary to give here, may have the same by applying to the writer.

In some instances, instead of the treatment of the soaked grain subsequently with hot water, hot air of equal temperature is recommended. The results obtained are just as satisfactory, and the system may have some advantages in reducing the time required for drying, but on the whole it is more complicated and requires apparatus which would have to be specially manufactured.

We have found the hot water treatment very satisfactory. The treatment itself is not too difficult to carry out with success, although the drying of the grain appears to us always a difficult problem. By mixing the wet grain with a quantity of perfectly dry road-dust or sawdust and sowing the same with it, it is possible to save time to some extent. Where this is done, the drill should be carefully adjusted to insure the sowing of the proper quantity of grain required for a good stand.

SMUT DISEASES OF BARLEY.

(Plate 4.)

Barley is subject to two forms of smut.—For a considerable time it was thought that barley was subject only to one smut disease. This position was taken by the older writers, who referred to barley smut by the name *Ustilago nuda*. When it was found, however, that the treatment applied to barley grain with a view to preventing smut produced rather contradictory results—in some cases eliminating the disease, in others, notwithstanding correct and careful treatment, rather increasing it—the view was at first held that the treatment after all had its limitations and was of restricted value as far as barley was concerned. Later, however, when a closer study became possible owing to the advance of our knowledge concerning flower infection, it was found that barley was subject to two distinct forms of smut, the one being a form of covered smut, *Ustilago Hordei* (Pers.) Kellerm & Swingle, and the other a true loose smut, *Ustilago nuda* (Jens.) Kellerm & Swingle. This discovery at once accounted satisfactorily for the failures experienced in some instances, viz., where loose smut was concerned, which naturally appeared at an increased rate owing to the seed treatment proving of no value.

Plate 4. The smuts of Barley. (a) Various stages of the loose smut of barley, (b) barley ear affected with covered smut.

3. Covered Smut of Barley.

(Plate 4, Fig. b.)

Appearance of the field.—Covered smut of barley is most readily recognised after the grain is cut. In the field the untrained observer is likely to mistake it for the loose smut, which it resembles at times rather closely. On carefully examining the ears, those affected with covered smut will be found considerably smaller in size than the sound ones. They are nearly of the same appearance as the sound ear; on looking closely at them, however, it will be found that there are no grains contained in the ear, but in place of them spore masses still covered with a fine, whitish membrane or skin, which is easily broken on slight pressure. There is no resemblance of this smut to stinking smut of wheat inasmuch as the grains are not free and enclosed in the glumes, but rather the whole flowering portion seems involved.

Spores disperse with threshing.—As in the case of stinking smut of wheat, the spores of covered smut of barley are generally liberated at the time of threshing. They will then contaminate the barley grains with which they are eventually introduced into the soil.

Germination of spores.—In appearance (plate 8, fig. 8), but particularly in germination, these spores differ from loose smuts and from stinking smut, which latter belongs to a very different group. We have briefly referred to the mode of germination of stinking and loose smut spores of wheat. In the former (*Tilletia*) we observed the 'wreath' of secondary pairs of conidia, in the latter there occurred no conidia but infection tubes were formed. In the covered smut of barley we may observe another mode of germination. The spores are slightly larger than those of loose smut of wheat, perfectly smooth and olive-brown. On being placed in nutrient solutions, they germinate freely, producing a short, stout germinal tube divided by septa into four cells. At these septa are produced or segmented a number of secondary conidia which multiply, even if detached, similarly to the mode of growth of brewers' yeast. Such cultures may be kept alive for a considerable time, during which the conidia increase in large numbers, but, on becoming exhausted, the secondary spores will produce the infection threads by means of which the fungus enters the living plant tissue. When sown with the barley, the spores causing covered smut eventually attack the germinating barley in the same manner as in stinking smut of wheat. We meet here with another case of seedling infection, hence the methods of control would have to be along the lines suggested for the smuts producing seedling infection.

Treatment.—Formalin treatment as recommended for stinking smut is of the greatest value for the form of smut described here. We do not advise treating barley with bluestone, which has been found injurious to the germination of barley to a far greater extent than in the case of wheat.

4. Loose Smut of Barley.

(Plate 4, Fig. a.)

The loose smut of barley is very closely related to loose smut of wheat. Taking into consideration its general symptoms and the life history of the fungus, one might be led to believe it to be the identical species found in wheat. Yet the fungi are biologically different, for the fact that the form from wheat cannot infect barley, and that found on barley cannot be induced to infect wheat, is significant enough in showing that the fungi are different species.

As in loose smut of wheat, this smut completely destroys the grain and the spores appear as loose powder at the time of flowering of the barley. In the earlier stages, the affected ear may resemble covered smut owing to a fine covering skin which may be present, but this skin is hardly ever found unruptured at harvest-time, when there will be left only the empty axil of the ear, and in bearded barleys the curved, twisted awns.

The life history is like that of loose smut of wheat. There are no secondary spores but more or less richly branched infection tubes which vary somewhat in breadth. The spores of this fungus (plate 8, fig. 7), though practically the same size as those of its near relative in wheat, show under the microscope one-half to be brownish in colour and the other distinctly paler, while the whole surface is finely dotted. The differences which are demonstrable are very slight.

The loose smut of barley produces flower infection only. The germ of the disease is carried within the barley grain. As regards control, the treatment recommended for loose smut of wheat applies in this case, i.e., the growing of selected grain on small plots, preceded by hot water treatment.

SMUT DISEASES OF OATS.

(Plate 5.)

Oat smut causes greatest loss.—Generally speaking, smut prevails in oats to a far greater extent than in wheat and barley. There is no excuse for suffering this to still further increase. There may be some excuse for the presence of loose smuts in wheat and barley, owing to the difficulty of controlling these smuts, but oat smut responds so readily to treatment that its presence may be regarded as a manifestation of neglect on the part of the farmer to thoroughly treat his grain before sowing.

Two smut fungi concerned.—In Canada we may observe occasionally two different smut fungi producing 'smut' in oats, viz., 'loose' or, better, 'naked' smut, to avoid confusion with the true loose smuts of wheat and barley, caused by the fungus *Ustilago Avenae* (Pers.) Jens., and 'covered' smut which is due to a closely related fungus, *Ustilago levis* (Kellerm. & Swingle) Magnus. The former is far more common. From their life history and their close biological relationship, we will see that both kinds of smut may be prevented on the same lines as suggested for stinking smut of wheat and covered smut of barley.

5. Naked Smut of Oats.

(Plate 5, Fig. b.)

Appearance in field.—This species of smut destroys the ears of oats, and appears in the form of an almost black powder while the plants are still growing. The first indications of its presence are the peculiarly stunted ears which develop in some instances. The normal ear will spread out far and carry its grain in a graceful manner; the diseased ear does not open out, but the glumes containing the spore powder stand erect and close to the centre axis. No doubt the ripening grain gaining in weight accounts largely for the spreading panicles. In some instances, the fungus is capable of growing on the uppermost leaf of the oat plant, enclosing the ear. We have observed recently a case where long black stripes were produced in the leaf tissue, which eventually burst open and contained masses of spores. This appearance reminds the investigator at first of the common 'leaf' smut in rye (*Urocystis occulta*).

Plate 5. The smuts of Oats. (a) Covered smut of oats; note the more natural appearance of the ear as compared with (b) showing the naked smut of oats.

Dispersal of spores before harvest.—The dispersal of the ripe spores takes place during the time of flowering, or at any rate before harvest-time. The spores (plate 8, fig. 2), are exceedingly light and are easily blown about when they will be caught by the loose, open glumes of the flowering oat plants in which they are held fast and become entrapped between the 'hull' and the kernel, as the latter increases in size. The amount of spores produced depends upon the rate of infection of a field of oats. When badly affected, the oat field will assume a much darker colour, owing to the presence of so many heads of smut. Where this is the case, the grain which is harvested will be badly infected with smut spores, and in oat smut we may regard the threshing machine as one of the most important factors for spreading the disease. It is very important not to permit the use of a threshing machine for any grain, whether oats, barley or wheat, unless the machine has been very carefully cleaned before it enters new premises.

Intensity of oat smut depends upon certain conditions.—When affected oats are eventually sown, without being treated for smut, the intensity of the outbreak is affected by certain climatic conditions which may prevail at the time of sowing. The maximum temperature at which oat smut spores germinate is comparatively high, hence, when the weather following the time of sowing is warm, the result may be a considerable infection, whereas if cold, the crop may be affected to a far lighter degree.

Germination of spores (plate 8, fig. D; 1-3).—The naked smut spore of oats is practically of the same size as the loose smut spores of wheat and barley, and resembles it in microscopical details, as, for instance, in being very finely dotted all over the surface. Its biological development, however, is similar to the covered smut of barley. On germination, the spore produces a septate promycelium, which produces a more or less large number of secondary hyaline conidia, which reproduce themselves, under favourable conditions, indefinitely, in a yeast-like manner. These conidia later on send out a germ tube by which the young oat plant becomes infected (Plate 8, fig. D, 3). The life of the spores is of long duration; records exist of their keeping alive for over seven years. From these observations, we may conclude that the immediate destruction of the spore would result in the control of this smut.

Method of control. Formalin preferable.—Owing to the protection of the oat by the hull, the bluestone treatment has not been found efficient, as a longer action of this chemical becomes necessary which will cause serious injury to the grain, whereas formalin possesses a sufficiently penetrative action and its application has controlled this smut very satisfactorily. The same treatment is recommended as described for stinking smut in wheat.

6. Covered Smut in Oats.

(Plate 5, Fig. a.)

Care in distinguishing principal features of smut diseases emphasized.—A thorough knowledge of the biology of the smut fungi is, of course, necessary for the adoption of correct methods of treatment. From the farmer's point of view, it is only necessary to recognize the various different kinds of smut which require different methods of treatment, i.e., it is most important to distinguish, for instance, between loose smut and covered smut of barley. A mistake may result in using formalin or bluestone in the treatment of loose smut, which we now know cannot be controlled by these means at all.

The two oat smuts closely resemble each other.—As far as the two kinds of smut in oats are concerned, their life histories are practically the same. The one is as

easily controlled by the formalin treatment as the other, and it matters little whether one or both have been present in the crop. But the young agricultural student who devotes some attention to the study of smut diseases should be well acquainted with their respective life histories, in order to intelligently interpret the reasons for suggesting certain methods for one smut, and others for a different kind. It is certainly a curious fact that the oat plant is subject to the attacks of two different smut fungi so much alike in appearance and habits of life, and yet microscopically distinct from each other. The covered smut of oats is closely related also to that of barley, but cross-inoculations have shown that the fungi will only grow on their respective host plants.

Covered oat smut spores disperse during threshing.—The covered smut of oats rarely sheds its spores before harvest-time, but the dispersal of the spores and the infection of the sound grain take place in the process of threshing.

Points of difference from naked smut.—After the oats are cut in the field the covered smut disease will manifest itself principally by the translucent spore masses occupying the place of the ripe grain and visible through a thin whitish membrane in otherwise quite normal ears. The spores are perfectly smooth when examined with a microscope, and not finely echinulate like the spores of naked smut of oats (plate 8, fig. 9) . Their germination and mode of infection, however, are identical with those of the former species. The whole differences of these two species are comprised in the smoothness of the spore in the one and the roughness in the other; and the different biological character, in the one producing an abnormal ear shedding its spores before harvest, and in the other in producing a normal ear and dispersing its spores during threshing.

Control with formalin.—Their control is the same. Formalin as described under stinking smut is generally employed.

7. Smut of Corn.

(Plate 6.)

Corn smut not confined to flowers.—While in the smut diseases of grain which have been described, the attacks of the fungi are almost exclusively confined to the 'ear' or inflorescence of the growing plant, the fungus causing corn smut produces symptoms very unlike any of the other smut diseases already dealt with. The presence of smut in corn requires little hunting for, owing to the characteristic 'smut boils,' often of enormous size, which are readily found on almost any part of the corn plant when the crop is attacked.

Discovery of first indications important.—The first indications of the corn smut should be carefully looked for, as the immediate removal of the affected plants, (or portions) before spores have been produced, is one of the important factors in preventing the dispersal of the spores, and at the same time in checking the spread to other corn plants in the field.

Smut boils may appear on any part of plant.—The first symptoms of corn smut may occur on any young and tender portion of the plant. The growing plant, the axils of the leaves where they are attached to the stem, the midrib of the young leaves, the male or female flowers, are the usual points of attack. In an early stage of development the attacked leaves look a paler yellow and are puckered with smaller or larger bladder-like swellings. These swellings contain, in the earlier stages, the masses of mycelium of the corn smut fungus (*Ustilago Zeae* (Beckm.) Unger.) which, after a very few days, will form abundant spores. Towards the time of spore production the

Plate 6. Smut of corn. (a) Male inflorescence partly infected. (b) A large "smut boil" on the main stem (c) Female inflorescence or "cob" destroyed by smut.

colour of the affected tissues becomes rather variable; we may often observe a deep crimson colour, which later gives way to a silvery-white. At this time, the spores are still unripe and enclosed within the irregular swellings covered by a stout skin, parchment-like in appearance, though much more pliable. As the disease progresses, the skin grows thinner and thinner and finally bursts, when myriads of spores in the form of an almost black powder will appear on the outside. When the 'ears' or the 'cobs' are attacked, considerable malformations take place. More or less large, round swellings may be produced in these localities, varying from the size of a pea to that of a walnut. These swellings are bladder-like to the touch, and sooner or later will be like pockets containing the spore powder; still later, this mass bursts the covering membrane and the spores are visible from the outside.

The corn smut spore (plate 8, fig. 5).—The corn smut spore is about twice the size of the loose smut spore of wheat or barley, with a fine, prickly surface, and often showing granulated contents. Its life history is similar to that of the covered smut fungi, inasmuch as it produces secondary conidia on germination, but it is very distinct from any of the other fungi described here, differing largely from them in the mode of infecting new plants.

New mode of infection.—We know that besides flower infection which takes place in the true loose smuts of wheat and barley, there is the 'seedling' infection in the case of the naked smut of oats and the covered smut of oats and barley. Although the progress of the smut in corn is so readily traceable, investigators have been greatly puzzled at finding that the spores produced no direct infection of the seedling or the young plant. Spores thickly sown with the corn seeds hardly ever produced that infection of the young plant which took place so readily in the case of the covered smut spores sown with oats or barley, or even in the case of stinking smut of wheat. It was later on discovered that infection took place almost exclusively above ground.

Brefeld's discoveries very important.—The careful and exhaustive researches of Brefeld again threw more light upon the subject. To this successful investigator the farmers in every country owe a great debt of gratitude; his painstaking researches and the discoveries he made, particularly in connection with the biology of smut fungi, which of course resulted in the adoption of the effective methods for control, now in practice all over the world, have saved many countries untold losses. Brefeld's methods of germinating and carrying on cultures of microscopic fungi have never, in our opinion, been surpassed. He succeeded in germinating the corn smut spores in nutritive solutions. Brefeld's investigations into the biology of this fungus have been successfully repeated in our experiments.

Germination of corn smut spores (plate 8, fig. E; 1-4).—On germinating the corn smut spore produces a short, stout promycelium divided into four sections, at the top and at each section of which there are produced a number of slender secondary conidia, a manner of germination which recalls that of the covered smut spores. The spores eventually become detached. The promycelium itself may separate and form more or less large clusters of yeast-like spores which multiply profusely. Their development in artificial cultures is so rapid and vigorous that soon spore-bearing branches are forced out into the air, where they will branch and produce spores in long chains (plate 8, fig. E; 4). These spores are considerably smaller than those produced within the artificial medium.

Spores do not cause direct infection—œrial conidia necessary.—Infection experiments in which the ordinary black spores were used, proved generally a failure, but if the spores were contained in a nutrient solution they began germinating rapidly; the

conidia produced formed, in a short time, a greyish film on the surface of the medium, and air conidia were produced subsequently. As soon as that was the case and the conidia were transferred by means of an atomizer (or throat sprayer) to the growing plant, an infection took place within some twelve days, provided the plant was young and tender; in which condition it is far more susceptible than, when growing older. the vulnerable spots become few and far between until the plant becomes altogether resistant when fully grown. From these observations, we may conclude that the ærial conidia are primarily responsible for the infection of the corn plant.

Weather affects smut.—Infection of the corn plant is aided by the condition of the weather. When the weather is very dry, corn smut is very rarely visible, but some ten days after a rainfall the first smut boils will appear. The moisture is not only necessary to start smut spores lying in the ground into active life, but also causes a rapid growth of the corn, especially after a long period of drouth, which results in the production of many tender spots at which an infection may take place.

Lessons from the life history.—The observations on the life history of corn smut teach several important lessons. It is shown that the infection takes place at almost any time on any part of the growing plant throughout the whole season. For this reason it is most important to remove the first signs of a forming smut boil, preferably before the spores are formed.

Remove affected plants or portions.—When removing plants which show the black spore powder, they should not be carried about the field, but the infected parts should be collected in paper bags and destroyed by fire.

Danger of throwing smut infected plants on manure pile.—It is hardly probable that a farmer will carelessly throw infected portions on the manure pile. This would be equivalent to introducing the spores into nutrient media, as done in our laboratory cultures. The moisture of the manure heap is one of the most favourable conditions for the development of the spores, where the secondary spores will go on growing throughout the year, even through the winter, the spontaneous heat of the manure heap preventing freezing. Such manure, when spread on the ground, especially in spring, will cause corn, planted thereon, to become badly infested. This is another point not to be forgotten in preventing corn smut.

Rotation of crops important.—Rotation of crops is another important factor in the prevention of corn smut. Spores resulting from an infected crop may lie in the soil over winter, germinate early in spring and spread the infection to the new crop should corn be again planted the second year.

Select seed corn from sound plants.—Care should also be taken to select the seed corn from a field which is free from corn smut. While no direct seedling infection takes place, the spores adhering to the corn may reach the surface of the ground, where they will germinate and produce air conidia, which as we know are necessary to commence or spread an attack.

Seed treatment unsuccessful.—Seed treatment for corn smut is not generally recommended, as the smut spreads mainly above ground. Brefeld has shown, however, that in experimental cases infection may take place below ground. Of 500 artificially infected seedlings, 20 succumbed owing to the development of a more or less large smut boil just above the crown of the root. In some such cases, the uppermost series of adventitious roots also became involved.

8. Broom Corn Smut.

(Plate 7, Fig. a, 1.)

Broom corn, the plant which yields the flexible long, upright 'seed heads' used in the manufacture of brooms or whisks in common use on the continent of America, is as yet little raised in Canada. During the last two years, experiments with broom corn were carried on at the Central Experimental Farm and some of the branch Farms. The first year of the experiment it was noticed that some varieties were fully 30 to 40 per cent smutted.

Smut interferes with quality of 'brush.'—Where broom corn is raised for seed, the smut of course seriously interferes with its production. For the purposes of broom-making, long, straight, thin 'brush' or seed heads are desired. The thick central axis which is sometimes produced renders the brush of inferior quality. Broom corn smut will prevent the production of useful 'heads.' The long, slender stalk desired will be found to be replaced by a short and curved one, and the undesirable central axis will be prominently developed. Smutty heads are entirely useless for seed or manufacturing purposes.

Seed production frustrated.—Our experience with broom corn smut proved the destructive nature of this disease which considerably interfered with the raising of usable 'brush.' The smut which was noticed was confined to the 'seed heads' or, to be more correct, to the reproductive parts of the flower, which normally would produce a seed. The production of seed was entirely frustrated, and the seed-bearing stalks forming the commercial product for the manufacture of brooms were twisted, short and stout.

Appearance of disease.—The affected heads showed, in the place of seeds, large, protruding, brown bodies (plate 7, fig. a, 1), which on breaking open with the fingers, were found to contain a spore powder similar to stinking smut of wheat in appearance, but without the unpleasant odour.

Smut of broom corn a distinct genus.—Microscopical examination of the spore powder revealed numerous olive-brown, roundish spores with a perfectly smooth surface and somewhat granular contents (plate 8, fig. 6). Their size approximated that of the oat smut spores. This form of smut is technically known as *Sphacelotheca Sorghi* (Link) Clinton, which is the third genus of smut fungi treated of in this bulletin. It differs from the first genus, *Tilletia*, principally in the mode of germination and in the size and shape of spores. From the second genus, *Ustilago*, it differs mainly by producing its spores around a central axis or columella and within a definite, more persistent membrane, whereas in *Ustilago* the spores are either entirely free or covered with a very thin, perishable membrane.

Germination of spores.—On germination, the broom corn smut spore behaves similarly to the covered smut spore of barley or oats. It produces the short piece of septate promycelium with secondary lateral or terminal conidia with very plain indications of attachment to the mycelium. In water, fusion of mycelial tubes occurs commonly. The secondary conidia multiply in a yeast-like manner in nutrient solutions. After exhausting the solution they produce delicate infection tubes.

Seedling infection.—When spores are sown with broom corn seed, the young seedling is infected directly by the germ tubes issuing from the secondary spores. In this respect, the broom corn smut infection is identical with those caused by the covered smut fungi of barley, oats, or naked smut of oats.

Control.—We have found in our experiments that the formalin treatment, especially the dipping method with removal of the floating smut balls, very satisfactorily controlled this disease. It reduced the high percentage of the year previous, to less than one per cent of the whole crop.

Plate 7. (a) Smut of broom corn (1) smut balls; (2) normal parts of ear enclosing sound grain; (3) sound grain of broom corn. (b) An ear of millet affected with smut.

9. Smut of Millet.

(Plate 7, Fig. b.)

The value of millet as a 'catch crop' becomes more and more realized. While by no means so heavy a yield is obtained as from corn, under certain conditions a trial of millet is advisable, especially when it is too late to sow corn. Its feeding value is nearly that of corn.

Millet, like most of the plants belonging to the 'grass' family, is subject to smut diseases, of which that due to the fungus *Ustilago Crameri* Körnicke, is the most common in this country.

Appearance in the field.—This smut somewhat resembles in appearance stinking smut of wheat or the covered smut of oats, and when growing in the field is very prominent from the black appearance of the affected heads. The spores are either dispersed in the field when they infect the seeds of neighbouring plants, as occurs in naked smut of oats, or they may remain enclosed in a membrane forming 'smut balls' similar to, but much smaller than, those of stinking smut of wheat.

Appearance and germination of spores (plate 8, fig. 3).—The spores are almost reddish-brown, some oval, some round or showing irregular indentations where they have come into contact with other spores when contained in the receptacle. They are quite smooth but their contents appear more or less granular. In size they are almost like the spores of corn smut. Their germination is similar to the latter or to any of the covered smuts described.

Seedling infection takes place.—The mode of infection also agrees with these latter kinds. When sown with millet seed, the spores germinate and affect the young millet seedling. For this reason, the correct treatment is one which destroys the spores adhering to the surface of the seed or present in the unbroken 'smut balls.' Formalin treatment, as described under stinking smut, has given great satisfaction, but care should be taken to remove the smut balls and to dry the seed very quickly, as it germinates rapidly when wet. Sprouted seeds should be sown immediately and not allowed to dry out.

Use good germinable seed.—In some experiments it happened that seed treated with formalin did not come up in the field, and on inquiring into the reason it was found that the seed was old and of low vitality. Fresh seeds are not affected by treatment. It is important to remember this, as the millets sold on the market are generally of low vitality.

BRIEF SUMMARY.

1. The diseases of cereals, corn, broom corn and millet, popularly known as smut diseases, are due to a number of parasitic fungi or plants of low organization.

2. These diseases are causing losses to the grain production of considerable magnitude. A conservative estimate of 5 per cent loss, in grain crops only, would amount to fifteen million dollars and more in one year.

3. The smut fungi, though apparently alike when considering the symptoms of disease, are microscopically and biologically distinct from each other. No infection of wheat takes place with smut fungi found on oats, barley, etc., and *vice versa.*

4. The study of the life history of the various smut-producing fungi must be considered as the underlying principle of the control of these diseases.

5. Investigation reveals three modes of infection of the host plants, viz.:—

(*a*) *Seedling infection,* which occurs in stinking smut of wheat, covered smut of barley, naked and covered smut of oats, broom corn and millet smut.

(*b*) *Flower infection,* which takes place in loose smut of wheat and barley.

(*c*) *Infection of any part of the plant,* during any period of its growth, which is known to occur in corn smut.

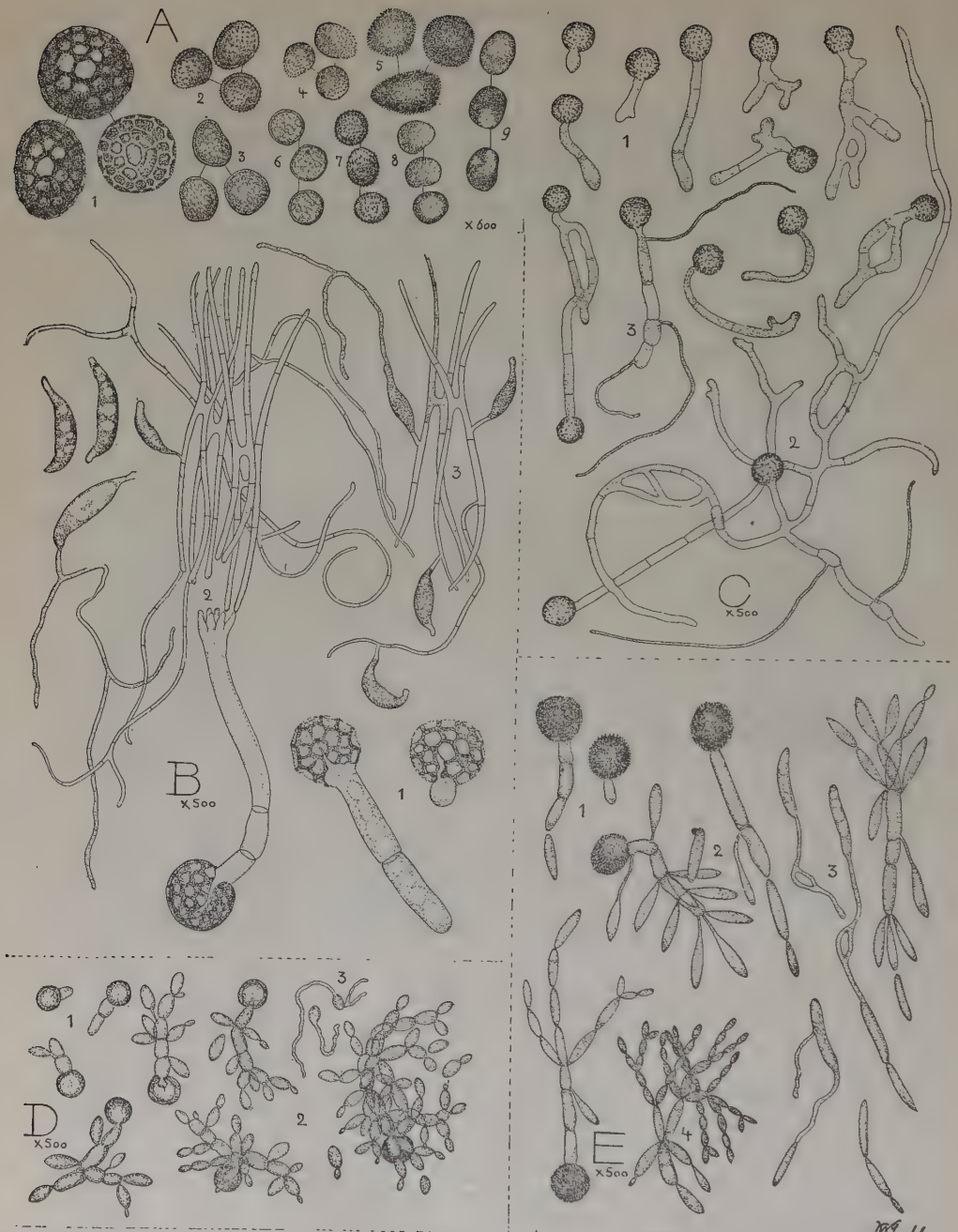

Plate 9. A 1—9 three spores of each kind of smut treated in this bulletin, all magnified 600 times. (1) Stinking smut of wheat, (2) naked smut of oats, (3) smut of millet, (4) loose smut of wheat, (5) corn smut, (6) broom corn smut, (7) loose smut of barley, (8) covered smut of barley, (9) covered smut of oats. B. Germination of stinking smut spores. (1) Early stages showing bursting of spore wall and promycelium growing. (2) Stout promycelium tube terminates in a crown of points at which the wreath of secondary sickle-shaped spores is produced, some of which are shown germinating. (3) Secondary spores producing tertiary spores and 4 tertiary spores enlarged, one germinating into infection tube. C. Germination of loose smut spores of wheat, (1) early stages, (2) a spore observed in artificial cultures for 12 days, (3) the promycelium produces thin infection tubes. D. Naked smut spores of oats germinating. (1) Early stages, (2) showing masses of secondary spores produced, (3) two secondary spores producing infection tubes. E. Corn smut spores germinating. (1) Early stages, (2) production of secondary spores, (3) secondary spores germinating, (4) production of air conidia from secondary conidia.

6. Smut diseases are perpetuated principally by spores. The wind dispersing the spores, spores adhering to the grain itself, or the living fungus within the grain, infected implements, grain bags, manure, and particularly uncleaned, smut-infected threshing machines, are the principal agents of the perpetuation of these diseases.

7. The vitality of the smut spores is of long duration—from 3 to 8 years in certain smuts—particularly in those in which seedling infection occurs, but is of shorter duration in the fungi causing loose smut.

8. Spores passing through the bodies of animals given smut-infected food are not totally destroyed. Hence the danger of reproduction of smut diseases by infected manure.

9. Animals fed experimentally with large quantities of smut spores, while not conclusively proved to suffer indisposition from such cause, are much better given clean food.

10. Soil infection from smut spores resting in the soil, or blown thereon, while not of great importance, has been proved to take place under favourable climatic conditions.

11. Satisfactory methods of control have been devised according to the biological features of the fungi causing the various smut diseases.

12. The treatment recommended is either directed towards bringing about the death of the spores adhering to the grain, or against the destruction of the living germs within the grain, and finally, as in corn smut, against the spread of the disease in the field, by the destruction of infected plants or infected portions of plants.

13. The first group of diseases in which the spores produce seedling infection is controlled by formalin or bluestone treatment of the grain, which is of no use whatever for the control of the diseases known as loose smut, in which the germ lives inside the grain. These kinds of smut may be controlled by application of the so-called hot water treatment.

Hot water treatment controls every kind of smut dealt with here, with the exception of corn smut. While the only means at present known to control loose smut diseases, it is, on a large scale, decidedly impracticable without the use of special machines or by means of co-operative practice. Farmers are advised to raise their own pure seed grain for sowing the main crop, when the labour of the hot water treatment will be minimized.

14. The formalin or bluestone treatment may be carried out in two ways: by steeping or by sprinkling. In most instances, formalin treatment is preferable. Bluestone treatment is recommended more or less as a substitute; it will give the same good results, but is slightly more troublesome in application and more liable to cause injury to the grain.

15. The solutions required should be made up and be used according to the following instructions:—

Bluestone solution.—Five pounds bluestone (commercial quality) to 50 Imperial gallons of water. (Note: No iron or tin vessel should be used for bluestone. This chemical dissolves slowly in water. By tying 5 pounds of bluestone crystals in a small bag and suspending it over night in a wooden barrel holding 50 gallons of water, it will be found dissolved in the morning.)

Formalin solution.—One pound of formalin (of normal strength = 40 per cent formaldehyde) to 40 Imperial gallons of water. Mix well by stirring. (Note: Before treating grain by any method see that it contains no unbroken smut balls. These should be removed in the fanning mill.)

STEEPING METHOD.

Fill bags half full of grain. Dip into either solution prescribed above, move bags slowly up and down several times to drive the air out from between the grains. Then keep the grain immersed and well covered by the solution used:

If in bluestone solution, not less than 2 minutes and not more than 3 minutes.

If in formalin solution, not less than 4 minutes and not more than 5 minutes. Take out bags, drain and spread out to dry. Neither the one nor the other of the solutions becomes exhausted in strength; they may be used over again as long as the quantity is enough to keep the grain wholly immersed.

SPRINKLING METHOD.

Either of the above solutions may be used without any modifications. Forty gallons of solution will suffice for 40 to 50 bushels of grain. Proceed as follows:—

Heap up the quantity of grain it is desired to treat, on a clean floor. Sprinkle solution over the heap with a broom or an ordinary sprinkling can. Shovel grain from this heap to another place, heaping it up again. This will evenly moisten the grain. Avoid drenching the seed by using too much solution. When thoroughly mixed, when using bluestone, spread out in a thin layer to dry. When using formalin, heap up the grain and cover the pile with bags or sacking for three hours to retain the fumes of the formaldehyde gas contained in the solution. Thereafter spread out to dry. When having to treat large quantities, heap up the grain towards one end in a grain wagon and sprinkle. Shovel over towards the other end, mixing the grain well with the solution. If too much moisture be not used, the grain will be in a fit condition for sowing the next morning.

(*Note.*—Neither bluestone nor formalin will destroy the living fungus germ inside the grain occurring in the loose smuts.)

DRYING AFTER TREATMENT.

When wet, the grain should not be exposed to temperatures below freezing (32° F.) or this will seriously injure the germination. On sunny days, spread out the grain in the open air in a thin layer and shovel over from time to time until it is dry enough to pass through the seed drill. Adjust your drill carefully, because the moist grain cannot feed the drill as freely as dry grain. Allowance should be made, or the stand will be too thin.

If the weather is unsuitable outdoors, spread the grain on the clean floor of the barn and treat in the same manner as practised outdoors. Always dry the grain as quickly as possible; if kept moist too long there is danger that it will germinate.

REINFECTION AFTER TREATMENT.

Avoid reinfection of treated grain. The spore dust will settle everywhere and, when stirred up, is liable to come into contact with the treated grain. As long as this grain is still wet there is no danger, but, when dry, if spores fall on it after the treatment, the whole labour is spoiled. It is desirable to spread out the grain for drying in some other place in which no smutty grain has been stored or handled, or re-infection is sure to result. Use entirely new bags when re-bagging treated grain. Or if not convenient, dip the old bags into either solution and dry, when they are fit to be used again.

HOT WATER TREATMENT.

(Principally for loose smuts of wheat and barley. Grain treated with hot water need not be subjected to any other treatment.)

(a) *Preliminary Treatment.*

Bring the temperature of a quantity of cold water in a barrel or tank, up to 86° F. by pouring in hot water until the thermometer registers 86° F. and not more

or less. Use a reliable thermometer. Fill the grain bag three-quarters full with grain and tie it up loosely. Immerse bag with grain into this water, moving it up and down several times. Allow grain to soak four hours. Should the temperature sink below 68° F. allow five hours for soaking. Treat preferably in a heated room to avoid the inconvenient fall in temperature of the water.

(b) *Final treatment.*

Bring the temperature of water in a second barrel up to 112° F. Remove bags with grain from the 'soak' and transfer to the second barrel. Keep immersed for 15 to 20 minutes. Meanwhile have water in a third barrel brought up to a temperature of 129° F. After the 15 to 20 minutes in the second barrel transfer the grain quickly into the third barrel. Here the grain remains a further 10 minutes. Under no circumstances extend the time stated, or shorten it. Neither be careless nor disregard accuracy of temperatures, or the treatment will not be successful. Should the temperature in the third barrel sink below 122° F. after the grain is put in, raise the temperature by carefully adding hot water from a sprinkling can. Never pour hot water directly on the grain. The larger the volume of water, the more easy will it be found to maintain the temperature. After the 10 minutes in the third barrel have expired, take out the grain, drain and spread out to dry.

TREATMENT FOR CORN SMUT.

Seed treatment of any kind is useless. Watch for the first symptoms of corn smut, remove either the whole plant or cut out below place of infection with a sharp knife. Destroy collected material by fire. Do not permit the spores to develop in the forming smut boil. The sooner this is destroyed, the more successfully will further spreading be prevented. Infested cornstalks should not be thrown on the manure pile where the spores will remain active even through winter, and the manure when spread on the land will reproduce the disease.

III.

APPENDIX.

DIRECTIONS FOR OBSERVING THE GERMINATION OF SMUT SPORES IN ARTIFICIAL CULTURES.

(*a*) COLLECTION OF THE MATERIAL.

The spores of some species of smut fungi are short-lived, while others may retain their vitality for a number of years, though naturally their energy of germination, as well as the percentage of germinating spores, gradually declines with the advance of age.

The spores of the true loose smuts, as of wheat and barley, lose their power of germination after a few months, and the failure to germinate any unknown species of smut after some months of storage, may be regarded in some instances as an indication of their producing flower-infection. Where this is experienced, the absence of secondary conidia will provide further proof. The spores of these fungi should be collected on a bright summer's day, when there is no moisture in the air or on the plants. The spore dust should be shaken into dry glass tubes and sealed with a well-fitting cork. As it sometimes happens that the spore supply spoils on subsequently becoming wet, a number of very small tubes should be separately filled, corked and kept in a stoppered glass jar for future use. This method will prevent the whole stock from being spoiled. The stock spores should be kept, preferably, in a cool place.

The spore material of stinking smut of wheat and certain covered or naked smuts of the genus *Ustilago* keep their germination for years, and, as long as the material is collected dry and preserved in this condition, failures to germinate the spores will rarely be experienced.

(*b*) PREPARATION OF NUTRIENT SOLUTIONS.

Most spores will commence germination in pure water, but in order to observe the production of secondary spores of *Tilletia*, for instance, water alone will not suffice. This is equally true of a number of other species of smut fungi. Practically every observer employs his own methods, which, depending on the condition of the spores, are accordingly more or less successful. In preparing the material for the original drawings in this bulletin the author tried various methods, until he found that the simplest possible composition of the medium used, gave invariable the best results. The medium for our cultures was obtained by placing a quantity of decomposed sod soil into a flask and adding distilled water to this until it covered the sod about one inch. The contents were freely stirred and three hours were allowed to make a cold extract from the soil. The soil was then drained and the extract filtered until quite free from any visible suspended impurities. The extract was then sterilized in the autoclave for 25 minutes, refiltered because of a slight deposit which will invariably form (excess of lime), and again autoclaved for 25 minutes on two consecutive days. This extract will keep indefinitely and is remarkably useful for germination experiments with spores of many other fungi, besides smuts.

(*c*) STARTING THE CULTURES.

Any kind of hollow-ground glass slide, Van Tieghem, or other life cell may be used. Heat the slide over a spirit flame until all condensed water disappears, place upside down on a clean pane of glass in a warm cupboard. Next clean large cover-glasses by simply wiping them with a clean cloth and flaming them for a second or two (No. 1 thickness, size 22 mm., circles or squares). Remove carefully a loopful

of soil extract with a sterile platinum loop and place it on centre of the cover-glass, and cover with an inverted watch-glass to keep the dust out. Take a sterile dissecting needle, dip it into the extract and touch very gently the spore mass of which it is desired to germinate individual spores. Gently touch with the infected needle the drop on the cover-glass, when sufficient spores will remain in drop. Avoid placing too many spores into the drop on the cover-glass. Take out the prepared hollow-ground slide, ring the edge with vaseline, place a small drop of the extract into the cavity and invert the spore-bearing cover-glass and press gently down on the vaseline ring. The slide is then ready for examination. The evaporation of the drop of culture medium at the bottom of the cell will provide sufficient medium for some time. But should it be desired to carry on the cultures for several months, it is advisable to carefully lift the cover-glass, say once a week, apply gently a small piece of absorbent filter paper to the edge of the drop, which will be readily taken up without spoiling the culture. Then replace the solution with a loopful of fresh extract and replace it on the slide. By a simple process one may observe the germination of a single spore. Place some spore material in a quantity of soil extract and mix well until all spores are wet and suspended in the water. Then sterilize an ordinary lithographic quill, dip into the spore-containing extract and place a number of small dots (6 to 12) in the centre of a clean cover-glass; it may happen that only one spore is contained in a sufficient number of these small drops, if not, dilute the material a little more, until each drop, or a large percentage of them contains only a single spore. Place the cover-glass, inverted, on the life cell, observe at regular intervals and make camera lucida drawings as the spore germinates.

(*d*) PREPARING PERMANENT SLIDES OF GERMINATING SPORES.

For class purposes and purposes of reference, the preparation of permanent slides showing the various stages of development will be found very useful. Some of the most beautiful preparations may be obtained with practice. Start, say, a dozen drop cultures at the same time. When the first symptoms of germination appear, and it is desired to preserve these, proceed as follows:—

Remove the cover-glass showing this stage, very gently—avoid its slipping or the preparation is spoiled. Place the cover-glass with the drop right side up and cover with an inverted watch glass, under the edge of which place a match or any other article to lift one side up and allow a passage for the air. In a short time the cover-glass will be quite dry. Do not use artificial heat for drying. Lift up the watch-glass and drop three or four drops of pure alcohol on the culture and allow it to evaporate. This will fix the material firmly enough for our purposes to the surface of the cover-glass. Next take the cover-glass up with a pair of forceps and immerse right side up into Xylol, rock gently to and fro until all traces of vaseline have disappeared. Remove and dry once more. The preparation is then mordanted for one minute. Use four grammes tannic acid, which dissolve under gentle heat in 16 c.c. distilled water; add 10 c.c. of a cold saturated solution of sulphate of iron and 2 c.c. cold saturated solution of fuchsin in 95 per cent alcohol. This solution should be prepared 24 hours before it is required, when its action will be more perfect. A single drop of this mixture is filtered on to the preparation, and it is allowed to act one minute. Pour off and rinse the cover-glass gently in distilled water to remove superfluous mixture.

Before quite dry, stain the preparation from 30 to 90 seconds, according to the desired depth, with a saturated solution of fuchsin in 95 per cent alcohol—one part in ten parts of distilled water. Again wash off the stain in distilled water until no more colour is removed, and dry in the air. When dry, mount in Canada balsam. If the culture has remained uncontaminated and the cover-glass was clean when starting, the preparation will be found satisfactory and will keep indefinitely.

Follow the same procedure with other stages of development of the spores under observation.

DESCRIPTION OF SMUT FUNGI DEALT WITH IN THIS BULLETIN.

The following key for identification of the smut fungi referred to in this bulletin will be found useful to the agricultural teacher and student. This review is adapted from Dr. George Perkin Clinton's '*Ustilaginales*,' North American Flora, Vol. 7, Part I, published by the New York Botanical Gardens, October 4, 1906, which we regard as the most up-to-date nomenclature on the subject. About 11 genera of the *Ustilaginaceæ* are known with some 120 species, while the *Tilletiaceæ* are represented by 8 genera including about 78 species. They occur on cultivated and wild grasses and a large number of other plants. Their importance diminishes with the economic value of the plants attacked.

Family 1. *USTILAGINACEÆ.*

Sori usually forming exposed dusty or agglutinated spore-masses. Germination by means of a septate promycelium, which gives rise to terminal and lateral sporidia (capable of yeast-like multiplication in nutrient solutions) or else to infection-threads.

Spores single.

Spore masses (sori) dusty when mature.

Without definite false membrane..... I. *Ustilago.*
With false membrane of definite fungus cells. II. *Sphacelotheca.*

I. *Ustilago* (Pers.) Roussel, Fl. Calvados ed. 2, 47, 1896.

Sori on various parts of the hosts, at maturity forming dusty, usually dark-coloured, spore-masses; spores single, produced irregularly in the fertile mycelial threads which early entirely disappear through gelatinization; small to medium in size; germination by means of a septate promycelium producing only infection-threads or with sporidia formed terminally and laterally near the septa; sporidia in water usually germinating into infection-threads but in nutrient solutions multiplying indefinitely, yeast fashion.

A. Spores reddish-, olive-, or black-brown.

1. Spores perfectly smooth, small, 4–10 μ in length. Sori in individual spikelets.

(*a*) Spores lighter-coloured on one side. Sori 6–10 mm. in length.
Hosts: *Avena*; spore-mass brown-black..... 1. *U. levis.*
Hosts: *Hordeum*: spore-mass purple-black .. 2. *U. Hordei.*

(*b*) Spores uniformly coloured. Sori usually destroying inner and basal parts of the spikelet..... 3. *N. Crameri.*

2. Spores echinulate or verruculose (occasionally minutely or obscurely).

(*a*) Spores, small 4–9μ in length. Sori in spikelets, rather completely destroying them.
Hosts: *Avena*..... 4. *U. Avenæ.*
Hosts: *Triticum*..... 5. *U. Tritici.*
Hosts: *Hordeum*..... 6. *U. nuda.*

(*b*) Spores medium, 9–14 μ in length. Sori on any part of host, usually very conspicuous .. 7. *U. Zeæ.*

1. *Ustilago levis* (Kellerm. & Swingle) Magn. Abh. Bot. Ver. Prov. Brand. 37: 69, 1896.

=*Ustilago Avenæ levis* Kellerm. & Swingle.
?*Ustilago Kolleri* Wille.

Sori in spikelets forming a black-brown adhering spore-mass, sometimes small and entirely concealed by the glumes, but usually evident, and destroying inner and basal parts; spores lighter-coloured on one side, subspherical or rarely more elongate, smooth, 5–9 μ, the most elongate rarely 11 μ in length.

Covered smut of cultivated oats.

2. *Ustilago Hordei* (Pers.) Kellerm. & Swingle, Annual Rep. Kan. Agr. Exp. Sta. 2: 268, 1890.

=*Uredo segetum Hordei* Pers.
Ustilago Hordei tecta Jens.
Ustilago Jensenii Rostr.

Sori in spikelets, forming an adhering purple-black spore-mass, about 6–10 mm. in length, covered rather permanently by the transparent basal parts of the glumes; spores lighter-coloured on one side, usually sub-spherical or spherical, smooth, 5–9 μ, the most elongate rarely 9–11 μ.

Covered smut of cultivated barley.

3. *Ustilago Crameri* Körn.; Fuckel, Jahrb. Nass. Ver. Nat. 27-28: 11, 1873.

Sori in the spikelets, infecting all of the spikes, ovate, about 2–4 mm. in length, chiefly destroying inner and basal parts; spores reddish-brown, chiefly ovoid to subspherical, though occasionally more elongate and irregular, smooth, with usually pitted contents, chiefly 8–11 μ in length.

Head smut of cultivated Italian millets

4. *Ustilago Avenæ* (Pers.) Jens. Charb. Cereales 4, 1889.

=*Uredo segetum Avenæ* Pers.
Ustilago segetum Avenæ Jens.
Ustilago Avenæ f. foliicola Almeida.

Sori in spikelets, forming a dusty olive--brown spore-mass, about 6–12 mm. long by half as wide, usually rather completely destroying floral parts, eventually becoming dissipated, rarely in leaves; spores lighter-coloured on one side, subspherical to spherical though often more elongate, minutely echinulate, 5–9 μ in length.

Naked smut of cultivated oats.

5. *Ustilago Tritici* (Pers.) Rostr. Overs. K. Danske Vid. Selsk. Forh. 1890: 15. (Mr. 1890.)

=*Uredo segetum Tritici* Pers.
Ustilago segetum Tritici Jens.
Ustilago Tritici Jens.
Ustilago Tritici f. folicola P. Henn.
Ustilagidium Tritici Herzb.

Sori in spikelets, forming a dusty olive-brown spore-mass, about 8–12 mm. long by half as wide, usually entirely destroying floral parts and eventually becoming dissipated and leaving behind only the naked rachis; spores lighter-coloured on one side, usually subspherical to spherical, occasionally more elongate, minutely echinulate especially on the lighter side, 5–9 μ in length.

Loose smut of cultivated wheat.

6. *Ustilago nuda* (Jens.) Kellerm. & Swingle. Annual Rep. Kansas Agr. Exp. Sta. 2: 277. (1890.)

=*Ustilago Hordei nuda* Jens.
Ustilago Hordei Rostr.
Ustilagidium Hordei Herzb.

Sori in spikelets, forming a dusty olive-brown spore-mass, about 6–10 mm. long by half as wide, temporarily protected by a thin membrane but soon becoming dissipated and leaving the naked rachis behind; spores lighter-coloured on one side, minutely echinulate, subspherical to spherical or occasionally more elongate, 5–9 μ in length.

Loose smut of cultivated barley.

7. *Ustilago Zeae* (Beckm.) Unger, Einfl. Bodens 211. (1836.)

=*Lycoperdon Zeae* Beckm.
Uredo Zeae Schw.
Ustilago Maydis Corda.
Ustilago Schweinitzii Tul.
Ustilago Zeae-Mays Wint.
Ustilago Euchlaenae Arcang.
Ustilago Mays-Zeae Magn.

Sori on any part of the host, usually prominent, forming irregular swellings from a few mm. to over a dm. in diameter, at first protected by a sort of false white membrane composed of plant cells and semi-gelatinized fungus threads, soon rupturing and disclosing a reddish-brown spore-mass; spores ellipsoidal to spherical or rarely more irregular, prominently though rather bluntly echinulate, 9–11 μ, the most elongate 15 μ in length.

Common smut of cultivated corn.

II. *Sphacelotheca* De Bary. Verg. Morph. Biol. Pilze, 187. (1884.)

=*Sporisorium* Ehrenb.
Endothlaspis Sor.

Sori usually in the inflorescence, often limited to the ovaries, provided with a definite (more or less temporary) false membrane covering a dusty spore-mass and a central columella (usually chiefly of plant tissues); false membrane composed largely or entirely of definite sterile fungous cells which are hyaline or slightly tinted, oblong to spherical, and usually more or less firmly bound together; spores single, usually reddish-brown, developed in a somewhat centripetal manner, small to medium in size, germination as in *Ustilago*.

Spores olive- or reddish-brown. Sori in ovaries. Spores 5–8 μ in length, smooth, 1. *S. Sorghi*.

1. *Sphacelotheca Sorghi* (Link). Clinton, Journal Mycology 8: 140. (1902.)

=*Sporisorium Sorghi* Link.
Tilletia Sorghi-vulgaris Tul.
Ustilago Sorghi Pass.
Ustilago Tulasnei Kühn.
Cintractia Sorghi-vulgaris Clinton.

Sori usually in the ovaries or the essential organs, forming oblong to ovate bodies 3–12 mm. in length, rarely fusing the very young spikelets into irregular forms, protected for some time by a false membrane but upon rupture the olive-brown spore-mass becoming scattered, leaving naked the distinct columella of plant tissue; sterile cells of membrane breaking up somewhat into groups, hyaline, oblong to subspherical, chiefly 7–18 μ in length; spores subspherical to spherical, smooth, contents often granular, 5. 5–8. 5 μ in diameter.

Grain smut of cultivated broom corn.

Family 2. *TILLETIACEÆ*.

Sori either forming dusty erumpent spore-masses or else permanently imbedded in the tissues. Germination by means of a short promycelium which usually gives rise to a terminal cluster of elongate sporidia that, with or without fusing in pairs, produce similar or dissimilar secondary sporidia or germinate directly into infection-threads.

Spores single, dusty at maturity. . . . . *Tilletia*.

Tilletia Tul. Ann. Sci. Nat. III, 7: 112. 1847.

Sori in various parts of the hosts, usually in the ovaries, forming a dusty spore-mass; spores single, usually formed singly in the ends of the mycelial threads that

disappear more or less completely through gelatinization, of medium to large size; germination with or without fusing in pairs, may, in nutrient solutions, give rise to a considerable mycelium bearing secondary air-sporidia.

Spores smooth. . . . . 1. *T. foetens.*
Spores reticulate, sori 5–8 mm. in length. . . . . 2. *T. Tritici.*

1. *Tilletia foetens* (B. & C.) Trel. Par. Fungi Wisc. 35. (1884.)
=*Ustilago foetens* B. & C.
Tilletia lævis Kühn.

Sori in ovaries, ovate or oblong, 5–8 mm. in length, more or less concealed by the glumes, all or only part of the ovaries of a spike infected; spores light- to dark-brown, oblong to chiefly subspherical or spherical, occasionally somewhat angular, fœtid especially when young, smooth, chiefly 16–22 μ, the most elongate rarely 28 μ in length.

Smooth spored stinking smut of cultivated wheat.

2. *Tilletia Tritici* (Bjerk.) Wint. Rab. Krypt. Fl. 1: 110. (1881.)
=*Lycoperdon Tritici* Bjerk.
Uredo Caries DC.

Sori in ovaries, ovate to oblong, 5–8 mm. in length, more or less concealed by the glumes; sterile cells few, hyaline, subspherical, with medium thin wall, smaller than spores; spores chiefly subspherical or spherical, light- to dark-brown, with winged reticulations about 1 μ high by 2–4 μ wide, 16–22 μ in diameter.

Rough spored stinking smut of cultivated wheat.

EXPLANATION OF BOTANICAL TERMS.

The use of botanical or scientific terms has been excluded as completely as possible from the pages of this bulletin. In the resumé of the genera and species, however, full use has been made of them. The student will meet the same terms in every text-book and should be familiar with them. The use of these terms insures accuracy and saves time and space. The terms are arranged alphabetically and their meaning is briefly explained. The following abbreviations have been also employed:—

'μ,' a letter of the Greek alphabet; used as a symbol in biology, denoting the unit of length. It is also referred to as 'micron' or micro-millimeter, and is equal to one-1000th of a millimeter or one-25000th of an inch.

mm.= millimeter = 0·0394 in.

dm.= decimeter = 10 centimeters or 3·937 in.

Angular, angular shapes or indentations in fungus spores, the result of pressure.
Anther, that portion of a stamen containing the pollen grains.
Autoclave, an apparatus used for sterilizing liquids or solids by superheated steam.
Centripetal, growing towards the centre from without.
Conidia, technical name for certain types of fungus spores.
Columella, small, pillar-like body of sterile cells within the sporangium or sorus of fungi.
Echinulate, showing minute prickles.
Ellipsoidal, oblong with uniformly rounded ends.
Elongate, oval, elliptical, or still longer in proportion to breadth.
Erumpent, bursting or pushing through the epidermis of the host plant from within.
Fertilization, the act resulting in the production of a fruit or seed.
Gelatinization, an expression describing the breaking down into a jelly-like mass of fungus hyphæ or membranes.
Genus, genera, the name of a group of plants or animals the species belonging to which all bear the generic name as the first portion of their scientific name.
Glumes, chaff-like portions of the flowers in grasses and cereals, which serve to protect the flower.

Host or host plant, the term used in plant pathology for any plant which entertains or feeds a parasitic organism.

Hyaline, colourless like clear water.

Inflorescence, comprising the flower or arrangement of flowers, or a shoot comprising one or more flowers.

Medium, media, in mycology or bacteriology the various substances, liquid, gelatinous, or solid, used for the artificial cultivation of fungi or bacteria.

Mordant, any substance preparing an object for the retention of colour. Objects difficult to stain, like flagella of bacteria, must be mordanted before they will take a stain.

Mycelium, the vegetative portion of a fungus plant, composed of threads known individually as hyphæ.

Ovary, a receptacle containing the ovules and from which the fruit is formed.

Ovate, egg-shaped.

Ovule, an immature seed.

Pale, the inner part of the two bracts or scales which enclose the individual flowers in the spikelet of grasses.

Pistil, female organ of a flower composed of the ovary or seed-case, the stigma or stigmas for the reception of the pollen, and usually of a connecting portion, the style or styles.

Promycelium, the more or less short, stout septate or unseptate mycelium produced on germination of the smut spores, either bearing secondary spores or producing germ tubes.

Rachis, the axis of an inflorescence.

Reticulations, marks or lines crossing like the meshes of a net; reticulated surface = surface with net-like thickenings.

Septum, septa, the dividing line or lines found in fungus mycelium. *Septate*, fungus mycelium may be divided (septate) or without division (non-septate).

Sorus, sori, somewhat incorrectly used in mycology to describe the erumpent or other kinds of spore-masses of fungi.

Spherical, round, circle-shaped.

Subspherical, almost but not quite spherical.

Spikelet, a cluster of one or more flowers enclosed by a common glume or pair of glumes.

Sporidia, same as conidia or fungus spore; generally used for small or secondary spores.

Stamen, the male part of the flower, composed of anther and filament (stalk).

Stigma, the terminal portion of the pistil which receives the pollen grains during fertilization.

Style, the elongated stalk-like portion of a pistil.

Verruculose, covered with warts.

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